Reports File

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT INITIATION

Date: July 6, 1971

Project Title: Sanitary Landfill Stabilization with Leachate Recycle

Project No: E-20-616

Principal Investigator: Dr. F. G. Pohland

Sponsor: Public Health Service (DHEW); Environmental Protection Agency

Agreement Period: From June 1, 1971 Until May 31, 1972*

*Support recommended for 02 year; application for continuation support (PHS Form 2590) required about 1/31/72.

Type Agreement: Grant No. 1 ROl EP 00658-01

Amount:
$23,500 PHS Funds (E-20-616)
1,239 GIT Contribution (E-20-315)
$24,739 Total Project

Reports Required: Quarterly Progress Letters; Interim Progress Report (with application for continuation support); Terminal Progress Report

Sponsor Contact Person (s):
Mr. Daniel J. Keller, Acting Chief
Research Grants - Solid Waste Research
Office of Research and Monitoring
Environmental Protection Agency
Cincinnati, Ohio 45213
Phone: (513) 684-4323

Assigned to: Civil Engineering

COPIES TO:

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RA-3 (6-71)

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GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT TERMINATION

Date: July 30, 1973

Project Title: Sanitary Landfill Stabilization with Leachate Recycle

Project No: E-20-616*

Principal Investigator: Dr. Frederick G. Pohland

Sponsor: Environmental Protection Agency, Washington, D.C.

Effective Termination Date: 6/24/73 (End Project Period)*

Clearance of Accounting Charges: by 6/30/73

Grant/Contract Closeout Actions Remaining:

Final (Annual) Report (6-1-71/6-24-73) by 9-24-73.
Report of Project Expenditures (Final Accounting).
Final Invention Report (within 90 days).
List of Equipment Acquired (if any). No equip budgeted

*Grant Amendment No. 1 withdrew most of previous no-cost extension and ended this Project Period one day before beginning of 03 year (separate project period). Follow-on project is E-20-642 (6-25-73/6-24-74).

Assigned to: School of Civil Engineering

COPIES TO:

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RA—4 (6—71)

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

SCHOOL OF
CIVIL ENGINEERING

TELEPHONE:
(404) 873-4211

September 8, 1971

Mr. David J. Keller, Chief
Research Grants
Solid Waste Research
Environmental Protection Agency
Office of Research and Monitoring
Cincinnati, Ohio 45213

Dear Dan:

Enclosed herewith find five copies of Quarterly Progress Report No.1 on my research project R-EP 00658-01, "Sanitary Landfill Stabilization with Leachate Recycle". The results to date look promising and will be documented in more detail by the special problem report being prepared by Mr. Larry Bortner and Mr. Bill Armentrout on this project. I will send you a copy of this report when it becomes available.

We enjoyed your brief visit with us last week and we look forward to your return in the future. Should you have any questions concerning the project, please do not hesitate to contact me at your convenience.

Best regards.

Sincerely,

Frederick G. Pohland
Professor of Civil Engineering

FGP:jw

SANITARY LANDFILL STABILIZATION WITH LEACHATE RECYCLE

Quarterly Progress Report No.1

R-EP 00658-01

September 7, 1971

Consistent with the objectives and research schedule provided in the original grant application, two 14-ft. high simulated landfills have been designed and constructed on the Georgia Tech campus. The units consist of 36-in. corrugated steel pipe lined with epoxy and placed upon a wooden platform. A conical concrete bottom seals the bottom of each column and allows for the collection of leachate in two epoxy-lined 55-gallon drums. Ten feet of manually compacted refuse prepared of selected refuse constituents were placed in each landfill column after being course ground with a brush chipper. Thirty inches of cover soil were added to the top of each column, compacted and covered with sod to simulate a final landfill cover.

Each simulated fill was brought to field capacity by the addition of tap water and the fills were then exposed to the normal rainfall of Atlanta. One of the columns served as a control; the other as a recirculating fill. Samples of leachate from the control fill were analyzed essentially after every rainfall on quantities resulting from a single pass of the rainfall through the fill. Collection of these samples was accomplished with a proportional sampling device geared to actuate upon accumulation of rainfall in the collection sump. Excess leachate after each rainfall was discharged to waste and the remainder utilized for sample analyses.

A 24-hr. composite sample was taken from the sump of the recirculating fill at weekly intervals with an automatic sample collector. The remainder of the leachate accumulating from each successive rainfall was recirculated continuously through the simulated landfill by pumping from the collection sump through a distribution lateral located at the top of the refuse fill and below the soil cover.

Three sampling ports were installed in each column to allow for the removal and analysis of refuse samples and the continuous monitoring of temperature within the fills. Rainfall and settlement have been measured and recorded after each rainfall period. Analyses have been performed on the initial refuse placed in the landfills, on the leaching characteristics of the soil cover with and without recirculation, on the leachate from each simulated fill, and for changes in refuse characteristics with time. Standard analytical methods ("Standard Methods") have been used for all analyses and include analyses for CHN, moisture content, organic and inorganic fraction, Kjeldahl nitrogen, K, Ca, Mg, Na and P on the original refuse sample; CHN, moisture content and volatile solids on the fill samples removed with time; Fe, Ca, Mg, Mn, Na, NH_3-N, TON, and TOC on the soil leachate samples; and, BOD_5, TOC, COD, TSS, VSS, TS, alkalinity, acidity, total hardness, total and ammonia nitrogen, nitrates, phosphates, Ca, Mg, Mn, Na, Fe, Cl^-, $SO_4^=$, pH and volatile acids on the leachate samples from the simulated landfills.

The data obtained from the preliminary analyses to date are not considered sufficient to warrant comprehensive evaluation at this time but do suggest a trend toward a more rapid stabilization in the recirculating fill. Additional data are being collected for evaluation which will be presented

in more detail later. Present emphasis is being placed on refinement of the analytical techniques and resolving some operational difficulties. Future effort will involve refinement of sampling and analysis techniques, automation, and preparations for construction of two additional units in line with the project objectives and schedule.

E-20-616

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

SCHOOL OF
CIVIL ENGINEERING

TELEPHONE:
(404) 873-4211

December 9, 1971

Mr. Daniel J. Keller, Chief
Research Contracts & Grants Branch
Solid Waste Research Division
Environmental Protection Agency
National Environmental Research Center
Cincinnati, Ohio 45268

Re: EP-00658-01

Dear Dan:

In accordance with our discussions during your visit at Georgia Tech, I would appreciate your consideration of a supplemental grant to our research project, EP-00658-01, "Sanitary Landfill Stabilization with Leachate Recycle". I have also included herewith five copies of Quarterly Progress Report No. 2.

Experiences to date have indicated a need for certain refinements to our experimental procedures as well as some alterations and improvements to the existing and proposed simulated landfills. Some of these needs have been documented in our quarterly and interim project reports.

The following improvements and changes not included in the original project request and award are considered justified, would greatly enhance the research effort and should be implemented with the construction of the two new landfill units.

A. Security: It is proposed to provide fencing and other appurtenances in and around the project area to insure security, protection and avoid tampering and possible loss of the experimental units and equipment.

1. Item: 6-foot high chain-link fence with gate (Sears, Roebuck & Company)
   Cost: $ 250.00

2. Item: Instrument shed (3'x4'x3' wood) to house temperature recorders, timers, samplers, etc. (Ga. Tech)
   Cost: $ 110.00

3. Item: Ladder and platform to replace rented scaffold and permit permanent and safe access to sampling ports and top of the simulated landfills. (Ga. Tech)
   Cost: $ 100.00

B. Instrumentation: It is proposed to refine sampling methods and analytical techniques to allow for more adequate accumulation of data and its interpretation.

1. Item: 300 gpm submersible pump and external automatic float switch to provide more durable and effective pumping to operate in conjunction with the automatic sampler associated with the control column. (W. W. Granger, Inc.)
   Cost: $ 30.00

2. Item: Three new sump pumps with plastic impellers to be used with recirculating fills to allow for leachate recycle and to minimize corrosion problems. (Sears, Roebuck & Company)
   Cost: $ 120.00

3. Item: Two industrial pH electrodes with mountings to provide continuous monitoring of pH and facilitate control of neutralization of recycled leachate in the simulated landfills. (Leeds & Northrop)
   Cost: $ 456.00

C. Construction and Landfill Modifications: Based upon experiences to date it is proposed to provide some alterations in the existing simulated landfills and to include these modifications in the new units presently under construction.

1. Item: Two sample ports per landfill column providing 3"-diam. access with removable metal covers to enhance visual inspection and sampling of the contents of the landfills. (Ga. Tech)
   Cost: $ 75.00

2. Item: Insulation composed of $1\frac{1}{2}$" fiberglass block-type with straps and covered by glass fabric and waterproof mastic to provide temperature control for landfill simulation. (Shook and Fletcher Insulation Company)
   Cost: $ 1040.00

3. Item: Painting of existing and proposed landfill containment vessels, scaffolding, platforms, instrument shed, etc. with porch and deck enamel. (Ga. Tech)
   Cost: $ 65.00

Total Amount Requested: $ 2246.00
(excluding overhead)

Your kind attention to this metter is appreciated and should you

require any additional information, clarification and/or format changes on this request, please contact me at your convenience.

Best wishes for the holidays.

Sincerely,

Frederick G. Pohland
Professor of Civil Engineering

Incl.
FGP/rsp

cc. Dr. William M. Sangster
Director-Civil Engineering

SANITARY LANDFILL STABILIZATION WITH LEACHATE RECYCLE

Quarterly Progress Report No. 2

R-EP 00658-01

December 9, 1971

In accordance with the objectives and research schedule provided in the original grant application, two 14-foot simulated landfills have been operated to determine the effect of leachate collection and recycle on the rate of stabilization within the fill together with the feasibility of using the fill as a treatment process for the leached constituents in the leachate. A review of the available literature has been completed and included with experimental data as part of a special research problem report (copy attached).

Preliminary results to date have indicated that the collection and recirculation of leachate through a simulated sanitary landfill resulted in a higher rate of landfill stabilization than was associated with a landfill constructed to permit rainfall-induced leachate to be collected but without recirculation. The concentration of most pollutants in the leachate from the recirculating landfill was lower than that found in the non-recirculating fill, however, pollutants were leached at a more rapid rate. An increased rate of biological activity was also observed in the recirculating landfill and resulted in the more rapid initiation of acid fermentation with its associated lowering of the pH and increasing concentrations of the various volatile acids. Acetic and propionic acids were the most prominent volatile acids much analogous to the behavior of an anaerobic digester undergoing acid production. At the present time both simulated fills are experiencing acid fermentation with little gas (methane) production being evident.

The two existing landfills will be operated for an additional six months to verify present trends as well as experiences elsewhere and to determine whether methane fermentation and hence leachate treatment and landfill stabilization will become established more rapidly with or without recycle. Moreover, the buildup of concentrations of the various

organic and inorganic pollutants in the leachates will be monitored to determine their magnitude and/or possible additional treatment requirements prior to ultimate disposal.

Two additional simulated landfills are presently being constructed to demonstrate the advantages and possible need for nutrient additions and/or pH control. The latter requirement is essential for the rapid initiation of methane fermentation and can be satisfied by an external neutralization and buffering with the addition of lime or other substances. The use of either raw or digested sewage sludges and lime-soda softening sludge to provide buffer capacity, nutrients and/or seeding requirements will also be explored together with controlled nutrient balances by the addition of nitrogen and phosphorous. Gas monitoring equipment will be installed and the sampling procedures so refined to permit more adequate control and removal of samples and for leachate analysis. Chemical and physical analyses will remain the same as indicated in the project methods. The new landfill units should be operational within the next quarter.

Frederick G. Pohland
Project Director

LIBRARY DOES NOT HAVE QUARTERLY PROGRESS REPORT NO. 3.

E-20-616

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

SCHOOL OF
CIVIL ENGINEERING

TELEPHONE:
(404) 894-2265

June 7, 1972

Mr. Dirk Brunner, Project Engineer
Solid Waste Research Division
Office of Research and Monitoring
Environmental Protection Agency
National Environmental Research Center
Cincinnati, Ohio 45268

Dear Dirk:

Enclosed herewith find five copies of Quarterly Progress Report No. 4 on my research project EP-00658-01, "Sanitary Landfill Stabilization with Leachate Recycle". We are very pleased with the results to date and will have a more comprehensive account of these in our annual report on the first year's effort.

We certainly appreciate your continued support of our research efforts and welcome your comments and/or recommendations. I hope you will have an opportunity to visit us soon, and I look forward to seeing you at the Engineering Foundation Conference later this summer. If any data or reports are available on the California leachate study, I would appreciate receiving them sometime at your convenience.

Best personal regards to all.

Sincerely,

Frederick G. Pohland
Professor of Civil Engineering

FGP:lb
Enc.

SANITARY LANDFILL STABILIZATION WITH LEACHATE RECYCLE

Quarterly Progress Report No. 4
EP-00658-01

June 6, 1972

In accordance with the objective and research schedule provided in the original grant application and recent supplement, four 14-ft. simulated landfills have been constructed and are being operated to determine the effect of leachate collection and recycle on the rate of stabilization within the fill together with the feasibility of using the fill as a treatment process for the leached constituents in the leachate.

Data have been collected and analyzed for a test period of 312 days on the first two landfill columns consisting of a control and a test unit receiving recirculated leachate. These data dramatically indicate the beneficial effect of recycle on the quality of the leachate. After about three months of operation, the pollutional characteristics of the leachate as measured by such parameters as BOD, COD, volatile acids, etc. began to be altered and reduced so that at the end of the indicated test period, the leachate was essentially stabilized. In contrast, leachate from the control landfill at the end of the test period continued to contain high and constant concentrations of organic pollutants. The changes recorded in the test parameters followed the predicted sequence of development of an initial acid fermentation followed by methane fermentation with respective productions of volatile acids and subsequent conversion of these acids

to methane and carbon dioxide.

Operation of these two units is continuing in an effort to establish the time required to allow for stabilization in the control unit exposed to receipt of natural rainfall. The two newer units are now operating with leachate collection and recirculation with netrualization and seeding with digested sludge to ascertain whether the stabilization process can be accelerated and encouraged to begin in less time than the 3-month period observed in the initial studies. Since these units have only recently been constructed and are undergoing start-up, no specific comments on experimental results can be made at this time. Most of the effort to date on these two units has been directed toward preparing the test refuse, charging the units and developing control procedures. Chemical and physical analyses on samples from these units will be similar as used for the initial units but will also include gas analysis and leachate neutralization control. Initial results should be available during the next quarter if continuation is granted.

Frederick G. Pohland
Project Director

E-20-816

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

SCHOOL OF
CIVIL ENGINEERING

TELEPHONE:
(404) 894-2265

November 9, 1972

all -
For your records

Mr. Dirk R. Brunner, Project Manager
Land Disposal Project
SWRD, ORM, EPA
National Environmental Research Center
Cincinnati, Ohio 45268

Dear Dirk:

Enclosed find five copies of Quarterly Progress Report No. 5 on my research project R-801397, "Sanitary Landfill Stabilization with Leachate Recycle". This report was delayed in order to permit reproduction of the most current student special problem report on the project. Two copies of this document are also included herein for your information. The quarterly report briefly summarizes this work which is presently being extended with the assistance of another graduate student in Sanitary Engineering at Georgia Tech.

Most reports indicate that the WPCF meeting in Atlanta was successful, and I hope Jim and Kent found it so also. It is unfortunate that I didn't have more time to spend with them but at least they had an opportunity to visit our facilities and learn about the project first hand. The research results are very encouraging and we are appreciative of your continued support.

I look forward to your visit in December and would suggest some time during the week of December 10-16, 1972 as convenient. I would be pleased to make arrangements for you here and will await further confirmation.

Best regards.

Sincerely,

Frederick G. Pohland
Professor of Civil Engineering

FGP:lb
Encs.

E-20-616

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

SCHOOL OF
CIVIL ENGINEERING

TELEPHONE
(404) 894-2265

January 25, 1973

Steve-
Do you get this also?
If not, who
now does?

Mr. Dirk R. Brunner, Project Manager
SWRD, ORM, EPA
National Environmental Research Center
Cincinnati, Ohio 45268

Dear Dirk:

Enclosed find 5 copies of Quarterly Progress report No. 6 on my research project R-801397, "Sanitary Landfill Stabilization with Leachate Recycle". Our progress to date has been very gratifying and has confirmed many of our initial assumptions. Because we may experience the possible persistence of certain residuals in the leachate, it may be desirable to extend the current studies beyond the present project period and to explore methods of treatment and ultimate disposal of these residuals when the majority of readily biodegradable material in the solid waste and leachate has been removed. We would therefore appreciate the opportunity to extend the present studies for at least a year with continued support from your agency. If this is considered appropriate, we would appreciate receipt of instructions and necessary forms for making application.

I hope to complete my review of the summary report on leachate analysis that you submitted to me in December in time for the training program project director's meeting with Wendell McElwee in Cincinnati on February 14-15, 1973. Perhaps you will be available for a chat then if time permits. I also intend to report on some of our research work at the Third Annual Environmental Engineering and Science Conference in Louisville in March and hope this meets with your approval.

Best regards to all.

Sincerely,

Frederick G. Pohland
Professor of Civil Engineering

FGP:lb
Enc.

SANITARY LANDFILL STABILIZATION WITH LEACHATE RECYCLE

Quarterly Progress Report No. 5
R-801397

September 1972

In accordance with the objectives and research schedule provided in the original grant application as amended, four 14-ft. simulated landfills have been operated to determine the effect of leachate collection, recycle, and neutralization and/or sludge seeding on the rate of refuse stabilization within the fill together with the feasibility of using the fill as a treatment process for the leached constituents in the leachate.

Data have been collected over a period of 398 days for the initial two fills consisting of a control and a test unit receiving recirculated leachate. Similar data have been collected for 95 days on the two additional fills which incorporate leachate recycle and leachate neutralization with and without raw sludge seeding respectively. These data have dramatically indicated the beneficial effect of recycle and pH control on the quality of the leachate as measured by such parameters as BOD, COD, TOC, Volatile acids, alkalinity, acidity, pH, and selected metals when compared to the control. The rate of stabilization of the refuse was enhanced and the total pollutional load potentially discharged to the environment was reduced.

The changes recorded in the test parameters followed the predicted sequence of development of an initial acid fermentation followed by methane fermentation with respective productions of volatile acids and subsequent conversion of these acids to methane and carbon dioxide. The

results also indicated that seeding with raw primary sewage sludge accelerated the decomposition process to the extent that acid production was exceedingly rapid and a deterrent detrimental to methane fermentation if allowed to promote pH inhibition and destruction of the methane formers.

Operation of the four columns is continuing to better establish trends and determine ultimate leachate quality with time. Instrumentation for pH control and neutralization is being employed and special attention will be given in subsequent periods to the leachate quality after most rapid stabilization has been completed together with alternatives for its treatment prior to final discharge.

Frederick G. Pohland
Project Director

Quarterly Progress Report No. 6

Research Project No. R-801397

"SANITARY LANDFILL STABILIZATION WITH LEACHATE RECYCLE"

September 1972 - December 1972
Georgia Institute of Technology
Atlanta, Georgia

In accordance with the objectives and research schedule provided in the original grant application as amended, four 14-ft. simulated landfills have been operated to determine the effect of leachate collection, recycle, and neutralization with and without raw sludge seeding on the rate and degree of solid waste stabilization within the fills together with the feasibility of using the landfill as a treatment process for the leachate.

Data have been collected over a period of about 550 days for the initial two fills (a control and test unit receiving recirculated leachate) and for about 250 days on the two additional units incorporating leachate recycle and leachate neutralization with and without seeding. These data continue to indicate the beneficial effect of recycle and pH control on the initiation of rapid decomposition and stabilization as measured by such parameters as BOD, TOC, COD, volatile acids, alkalinity, acidity, pH and selected metals.

The changes recorded by the test parameters followed a trend predictable by the recognized sequence of events occasioned by an initial acid fermentation followed by methane generation with respective production of volatile acids and subsequent conversion of these acids to methane and carbon dioxide. The results have also indicated that seeding with raw sewage sludge accelerated the decomposition process to the extent that acid production was exceedingly rapid and a deterrent detrimental to methane fermentation if allowed to promote pH inhibition and/or destruction of the methane formers. This production of acids could be controlled by neutralization with caustic soda until the population of methane formers was sufficient to utilize these acids at a rate similar to the rate of production. At this point, the continued addition of buffer was not required, and the system with sludge seed began to perform as a well adjusted methane fermentation process.

Operation of the four simulated landfills is continuing to better establish trends and to determine ultimate leachate and solid waste quality with time. Consideration of methods for treatment and/or disposal of persisting residuals will be evaluated and may lead to justification for extension of the present research effort beyond the current project period. Some exploritory work on treatment of leachate residuals has commenced and an abstract describing some fo the initial efforts has been submitted for presentation at the Purdue Industrial Waste Conference

in May 1973. In addition, the project director will present a partial account of project accomplishments at the Third Annaul Environmental Engineering and Science Conference at the University of Louisville in March 1973.

Frederick G. Pohland
Project Director

1/22/73
FGP:lb

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

SCHOOL OF
CIVIL ENGINEERING

TELEPHONE:
(404) 894-2265

July 11, 1973

Mr. Dirk Brunner, Project Manager
SWRD, ORM, EPA
National Environmental Research Center
Cincinnati, Ohio 45268

Dear Dirk:

Enclosed find five copies of a report of progress on my research project R-801397, "Sanitary Landfill Stabilization with Leachate Recycle" covering the period December 1972 through May 1973. I regret that this report was delayed, but in view of some of the uncertainties associated with project extension and continued funding, we had devoted most of our effort to the research and preparing for the final report. This report of effort for the past two years should be available within the near future and on schedule.

We are pleased with our progress to date and are appreciative of your continued support of our efforts. We are still looking forward to a visit from you sometime and hope to maintain the benefits of continued contact with your group.

Best regards.

Sincerely,

Frederick G. Pohland
Professor of Civil Engineering

FGP:lb
Encs.

Quarterly Progress Report (7 & 8)

Research Project No. R-801397

"SANITARY LANDFILL STABILIZATION WITH LEACHATE RECYCLE"

December 1, 1972 - May 31, 1973
Georgia Institute of Technology
Atlanta, Georgia

In accordance with the objectives and research schedule provided in the original grant application as amended, four 14-ft. simulated landfills have been operated to determine the effect of leachate collection, recycle, and seeding on the rate and degree of solid waste stabilization within the fills together with the feasibility of using the landfill as a treatment process for the leachate.

Data have been collected over a period of 720 days for the initial two fills (a control unit without leachate recirculated and a test unit with recirculated leachate) and for about 420 days on the two additional units incorporating leachate recycle and leachate neutralization with and without raw sludge seeding. These data continue to indicate the beneficial effect of recycle and pH control on the initiation of rapid decomposition and stabilization as measured by such parameters as BOD, TOC, COD, volatile acids, alkalinity, acidity, pH and selected metals. These data are presently being tabulated and analyzed in more detail as part of the final project report on the first two years of research study.

In general, the changes recorded by the test parameters continued to follow a trend predictable by the recognized sequence of events occasioned by an initial acid fermentation followed by methane generation with respective production of volatile acids and subsequent conversion of these acids to methane and carbon dioxide. The results have also indicated that seeding with raw sludge accelerated the decomposition process to the extent that acid production was exceedingly rapid and an initial deterrent detrimental to methane fermentation if allowed to promote pH inhibition and/or destruction of the methane formers. This production of acids could be controlled by neutralization with caustic soda until the population of methane formers was sufficient to utilize these acids at a rate similar to the rate of production. At this point the continued addition of buffer was not required, external neutralization was discontinued, and the unit which had originally received the sludge feed began and is continuing to perform as a well adjusted methane fermentation process.

During this project period, operation of the four simulated landfills continued to better establish trends and permit determination of ultimate leachate and solid waste quality with time under the respective operational modes. In addition, samples have been collected and stored to allow consideration of methods of treatment and/or disposal of persistant residuals. Some exploritory investigations on treatment of leachate residuals has commenced and will be extended through the new award period.

A partial account of efforts during the project period was presented at the Third Annual Environmental Engineering and Science Conference at the University of Louisville in March and additional presentations are scheduled for the October WPCF meeting in Cleveland and at a special seminar at the University of Florida in November.

Frederick G. Pohland
Project Director

E-20-616

Interim Progress Report

LANDFILL STABILIZATION WITH LEACHATE RECYCLE

by

Georgia Institute of Technology
School of Civil Engineering
Atlanta, Georgia 30332
Dr. F. G. Pohland, Project Director

for the

SOLID WASTE RESEARCH DIVISION

Environmental Protection Agency

Project #EP00658-01
Grant Period: 6/01/71 - 5/31/72

March, 1972

ABSTRACT

The information presented in the interim progress report has resulted from initial studies on the feasibility of a leachate recycle system which will provide leachate treatment and pollution control as well as accelerated rates of biological stabilization within sanitary landfills. The specific aims of the total project are: (a) to study and demonstrate the feasibility of increasing landfill stabilization rates and provide concomitant leachate treatment by leachate capture and recycle through a simulated sanitary landfill; (b) to identify and develop control parameters and techniques including methods for determining rates of decomposition and stabilization in the landfill, rates of accumulation and/or disappearance of intermediates and end-products in the leachate, and the extent and type of internal or external control necessary to maintain an optimum environment within the fill; and, to provide recommended design, operational and control methods applicable to conventional sanitary landfill practice.

In the phases of the study reported herein, four simulated landfill containment vessels and support structures have been designed and constructed, the test refuse has been prepared and placed, operational procedures have been developed, and sampling and analysis of samples from both the control and recirculating landfills have been undertaken. The preliminary results have indicated that if leachate recirculation is practiced, leachate produced by a landfill must be collected and contained until the fill has completed its most rapid biological stabilization processes. When this has occurred, the collected leachate could be discharged directly into the environment or treated and then discharged depending upon prevailing conditions. Recirculation of leachate through the simulated landfills has reduced the concentration of extracted materials in the leachate and thereby provided a new method of environmental control of potential utility to the management of solid waste disposal systems.

Additional studies are being conducted in accordance with the research plan originally proposed in order to substantiate existing trends and explore the possibility of providing operational control in the form of pH modification, seeding and/or nutrient additions. Stabilization rates and leachate characteristics will again be documented and will be supplemented with temperature control and gas monitoring.

CONTENTS

FIGURES

TABLES

SECTION I

CONCLUSIONS

1. The collection and recirculation of leachate through a simulated sanitary landfill resulted in a higher rate of landfill stabilization than was associated with a landfill constructed and operated without recirculation.
2. The eventual concentration of most pollutants in the leachate from the recirculating landfill was lower than that found in the non-recirculating landfill and pollutants were leached and/or attenuated at a more rapid rate.
3. The increased rate of biological activity observed in the recirculating landfill was caused by the equalizing effect of leachate recirculation on the environment within the fill.
4. The recirculation of leachate through a sanitary landfill does not lower the temperature in the fill below the optimum range for mesophilic organisms.
5. The ultimate effect of leachate recirculation is the reduction in total pollution eventually discharged to the environment by a landfill and the improvement of the sanitary landfill method of solid waste disposal as a land reclamation method.
6. The present study should be continued to verify the trends observed during the first 197 days and additional recirculating fills should be constructed and used to evaluate the effect of seeding and/or pH and nutrient control as supplemented by monitoring and temperature control.

SECTION II

RECOMMENDATIONS

The data to date have shown several basic trends which imply that leachate recirculation will increase the rate of landfill stabilization, reduce the concentration of organic pollutants in the leachate and permit ultimate discharge with or without treatment. Continuing research is needed to verify the existing trends and to determine if inhibitory substances will accumulate in the recirculated leachate. Two additional simulated recirculating fills being constructed should determine the effect pH control and nutrient addition might have on the process. Installation of gas monitoring equipment and larger sampling ports will also provide supporting information.

Operation of the initial two simulated landfills should be continued for an additional 12 months to verify the trends observed during the first study phase. The additional operating period should allow the observation of the accumulation of any inhibitory materials in the leachate or fills. The two new recirculating fills should be constructed with flexibility to demonstrate the value of pH control and/or nutrient addition. The initial pH in the recirculated leachate was well below the optimum range for the methane forming bacteria indicating that stabilization went through the acid fermentation stage followed subsequently by methane fermentation. The small quantity of organic nitrogen present in the synthetic refuse may also have been a limiting factor in stabilization and the addition of a nitrogenous source should prove valuable. Control of pH may be achieved by placing layers of limestone at intervals in the fill material or adding lime or other neutralizing materials to the recirculating leachate. The addition of nutrients may be achieved by mixing digested sludge with the synthetic refuse or adding fertilizer to the

recirculating leachate.

Gas monitoring equipment installed on both the new and existing simulated fills will provide measurements of the gaseous reaction products when they are generated. Larger sampling ports should also be installed to allow larger and more representative solid waste samples to be removed from the fills and to permit visual comparison of the refuse in the new and existing fills.

SECTION III

INTRODUCTION

The sanitary landfill method of solid waste disposal has been used to economically dispose of waste generated by both metropolitan and rural communities and also to reclaim unsuitable land for recreational and other uses. However, the potential for land reclamation has not yet been fully realized due primarily to the time required for the fill to stabilize (often twenty years or longer).

Documentation of several instances of ground and surface water pollution by leachate and surface runoff from sanitary landfills has resulted in construction and operation criteria often requiring the exclusion of surface runoff and ground water from landfills. Diversion of all moisture except direct precipitation from a landfill results in much less leachate production, but also reduces the rate of biological stabilization due to a lack of moisture and necessary nutrient transport. This retardation of biological activity in the fill results in an extension of the period required for stabilization, thereby limiting and/or delaying plans for land reclamation and ultimate use.

It was the purpose of this research to demonstrate that the collection of leachate and its recirculation through a simulated landfill would:

1. increase the utility of the sanitary landfill as a solid waste treatment and land reclamation process by increasing the rate and predictability of biological stabilization; and
2. reduce the quantity of organic and inorganic pollutants in the leachate by utilizing and controlling the biological activity within the fill.

SECTION IV

REVIEW OF THE LITERATURE

Whenever refuse is deposited on land, some of its organic and inorganic constituents are subject to leaching as water percolating through the refuse carries these materials into aquifers, surface streams or impoundments. Such leaching of pollutants may seriously impair water quality and endanger the health and welfare of the community.

The leachate formed by such action has been defined as the contaminated liquid which is discharged from a landfill to either surface or subsurface receptors[10]. For pollution of ground water to occur, three conditions are required: (1) the refuse must be located over, adjacent to, or in an aquifer; (2) supersaturation must exist in the fill due mainly to the movement of ground water into the fill and percolation of precipitation and surface water runoff; and, (3) leached fluids must be produced and this leachate must be capable of entering an aquifer[21].

Effect of Landfills on Water Quality

Based on the study of an existing landfill in an abandoned gravel pit, Anderson and Dornbush[1] reported that ground water in the immediate vicinity of the landfill and in direct contact with the fill exhibited an increase in ionic strength and that the impairment of water quality by excess ions decreased with distance from the fill area. Analyses on the samples obtained at various depths from 22 wells located around the landfill indicated that the concentration of chlorides and sodium and the specific conductance were the most appropriate chemical parameter of these employed to measure to leachate pollution. It was also reported

that the pond downstream from the fill area served to reduce the hardness and alkalinity during the summer months.

Hughes, et al.[14-17,29] investigated the characteristics of four active landfills of varying ages in northeastern Illinois. Piezometers were installed at various points in the landfills and core samples were obtained at the piezometer locations. The results indicated that ground water mounds had formed under each fill and that leachate moved away from the fill area through springs in the superficial sand layer around the fills and vertically downward into the subgrade. Analyses of samples revealed that ground water quality increased with age of the fill material and with distance from the fill area. Ground water quality also varied greatly over short vertical and horizontal distances within the fill.

Coe[5] reported from studies at the University of Southern California that the ground water under the Riverside Landfill contained BOD, chloride, sodium, and sulfate increases of 26, 10, 9 and 8 times respectively over the concentrations found in the natural and uncontaminated ground water. In general, the ground water at all points sampled downstream of the fill showed significant increases in mineral constituents, hardness, and alkalinity; however, the effects were considerably less than those found in ground water under the fill.

Calvert[2] reported an increase in hardness, calcium, magnesium, total solids and carbon dioxide in a well 500 feet from a refuse storage pit at a garbage reduction plant. Carpenter and Setter[3] sampled water at the bottom of a refuse fill and obtained average BOD, alkalinity and chloride concentrations of 1,987 mg/l, 3,867 mg/l, and 3,506 mg/l respectively. Lang[18] reported the pollution of well water 2,000 feet away from a fill.

The pollution of the surface water supply of Kansas City, Missouri reported by Hopkins and Popalisky[13] was attributed to the reactivation of an industrial waste landfill with the subsequent leaching of organic compounds directly into the Missouri River one mile above the city's water intake. A review of German experiences[19] has indicated the detection of pollution in surface waters 2.5 miles downstream from a solid waste disposal area.

Quantities of Leachate Produced by Landfills

Remson, et al.[24] have developed a moisture routing model based on the equation of continuity to predict the quantity of leachate which would be produced by a landfill for a given refuse, soil, and precipitation pattern. Sample calculations for a hypothetical landfill composed of eight feet of compacted refuse and two feet of soil cover were provided together with characteristics of a municipal refuse. Calculations were simplified by assuming: (1) a fully vegetated fill surface with plants whose roots draw water from all parts of the soil cover but not the underlying fill; (2) no moisture removed by diffusing gases; (3) infiltration of all rainfall; (4) a soil cover and refuse with uniform hydraulic characteristics in all directions; and, (5) a freely draining landfill and substrata. The examples assumed instantaneous placement of a refuse at various moisture contents and at various times of the year. The average rainfall was superimposed and the amounts of leachate produced calculated.

A graphical phase relationship presented by Fungaroli[10] showed a definite lag between initial addition of water and the production of leachate as well as a correlation between water added and leachate

produced. The relationships between field capacity and dry density of the refuse and the effect of cover soil type on infiltration into the fill indicated that denser refuse yielded higher field capacity and therefore a longer time to saturate the landfill and produce leachate. A light clay loam proved to be the best cover material because of the longer time required to bring a given thickness to field capacity and allow percolation into the fill. It was concluded that leachate production could be attributed to refuse composition and placement, channeling and/or type of wetting front.

Experiments by Merz and Stone[19] with landfill cells of approximately 20 feet in depth and covered with two feet of earth indicated that little leachate percolated into the subgrade beneath the landfills. Water was applied in sufficient quantities to the refuse cells by a sprinkler system so as to augment the natural rainfall and match the yearly rainfall of Seattle, Washington for one cell and to provide enough water to allow the growth of a thick turf on the other. The moisture content of the soil cover, refuse and subgrade was obtained from core samples taken at various points in the cells. Differences in moisture content at different levels (bands) in the cells were noted. Except for the soil cover, the top band of the cell simulating rainfall patterns of Seattle, was always drier than the other bands. During the final year of the project, the middle band maintained a higher moisture content than the bottom band thereby indicating that the fill material had a high holding capacity. The adobe-shale subgrade beneath the cell maintained a moisture content only seven percent greater than native soils taken from the same depth. The earth cover of the other cell had a lower moisture content

than the three bands at all times except for two core samples. There was no relationship between the moisture content of the top and middle bands and the subgrade averaged about the same water content as observed before for the other cell until it was accidently flooded. After flooding, the moisture content of the subgrade increased 38 percent.

Characteristics of Leachate Produced by Landfills

Theoretically any time that the amount of water entering a fill exceeds the field capacity of the deposited refuse, leachate will be produced and discharged. Leachate characteristics vary widely and there is no general way to forecast the exact composition of leachate which may be associated with a fill at any time. They are influenced not only by the material in the fill but also the chemical and physical characteristics of the percolating water and the soil adjacent to the fill or used for cover[25]. In almost all instances, leachate will be composed of concentrations of pollutants in the form of dissolved and finely suspended solids and microbial waste products[12].

Several studies have been performed to ascertain the characteristics of leachate. Coe[5] reported that the color of leachate ranged from green to brown, and that odors were similar to those of garbage (decomposing food stuffs) and oil and grease (hydrocarbons). Qasim[22] noted that the initial leachate samples were dark green and became darker and septic soon after collection.

Qasim and Burchinal[22,23] have reported experimental results obtained from examination of leachate produced from simulated landfills consisting of 36-inch concrete cylinders containing municipal refuse and

covered to exclude precipitation. Water was applied by an internal sprinkling system and leachate samples were collected and analyzed for alkalinity, acidity, pH, BOD, total hardness, calcium, magnesium, sodium, potassium, iron, sulfate, phosphate, chlorides, nitrogen, solids, tanin and lignin, coliforms and total plate counts. Leachate analyses indicated an initial increase of pollutants which decreased after four weeks depending upon the depth of fill and extent of stabilization. The deeper fills took longer to become saturated so that leaching started later. Moreover, leachate liquors from the deeper fills were stronger although concentrations of pollutants per foot of fill decreased as the depth of fill increased.

Fungaroli and Steiner[11] have reported the results from examination of leachate from an insulated lysimeter. The leachate was generally acidic with the usual pH range between 5.0 and 6.5 except for some high and low peaks. Erratic pH occurred during low leachate production whereas relatively constant pH corresponded to periods of large production. This implied that the volumetric flow rate of leachate through the refuse was a moderating factor for pH. In addition, during low flow periods when the pH was greater than 5.5, the iron concentration in the leachate was low, about 100 mg/l. Conversely, when leachate production was high and the pH less than 5.5, the iron concentration was high. The maximum concentration for both ferric and ferrous iron exceeded 1600 mg/l. The quantity of leachate produced also influenced the total solids concentration. The total solids increased with increasing leachate volume and decreased with decreasing volume. This indicated the "washing-action" as the leachate moved through the refuse. Similarly, after the initially high concentration of 50,000 mg/l COD, the COD remained between 20,000

to 22,000 mg/l during the duration of the two-year study. The leachate was also analyzed for chlorides, copper, zinc, nitrogen, phosphate, sodium, sulfate, and hardness; however, no trends or interrelationships between various ions were apparent.

Merz[25] reported results from examination of leachate from two "percolation bins" containing ten feet of compacted domestic refuse. The concentration of the organic and inorganic components was high in the first samples of leachate and increased for five weeks. The initial BOD was 33,100 mg/l and remained high for eight months. An 80 percent drop in BOD occurred after eight months and after 13 months the BOD had been reduced to 375 mg/l. The maximum ion concentration in the leachate was 10 to 20 times the concentration found in the water applied to the refuse. The ammonia, organic nitrogen and phosphate concentrations of the leachate were as much as 10,000 times the concentration found in natural waters. It was concluded that continuous leaching of an acre-foot of fill would result in minimum extraction of about 1.5 tons of sodium and potassium, 1.0 ton of calcium and magnesium, 0.91 ton of chlorides, 0.23 ton of sulfates, and 3.9 tons of bicarbonate. Removals of these quantities would take place in less than one year after which removals would continue slowly with some ions always remaining.

Table I contains the results of several leachate studies. These results are influenced by differences in refuse and percolating water and by limitations in sampling and analytical technique.

Parametric Considerations of Landfill Stabilization

One of the important parameters to be considered in a landfill is the moisture content of the material as placed. Refuse usually contains

Table 1

Variations in Leachate Composition

Analysis*	1	2	3	4	5	6	7	8	9	10	11	12	13	14		15	16	17
pH	5.6	5.9	8.3	-	-	-	-	-	7.63	5.60	7.4	6.4	4.9	5.6	8.4	5.7	6.3	6.48	5.88
Total Hardness (as $CaCO_3$)	8,120	3,260	537	-	8,700	500	900	290	8,120	650	-	-	2,500	30	-	-	7,600	13,100	10,950
Total Alkalinity (as $CaCO_3$)	8,100	1,710	1,290	-	-	-	-	-	9,520	730	-	-	-	-	9,450	100	10,630	16,200	20,850
Total Iron	305	336	219	1,000	-	-	40	2	305	6	-	206	152	28	-	-	175	546	860
Sodium	1,805	350	600	-	-	-	-	-	1,805	85	-	1,200	1,100	300	-	-	584	1,428	1,439
Potassium	1,860	655	-	-	-	-	-	-	1,860	28	-	-	920	110	-	-	1,050	2,535	3,770
Sulfate	630	1,220	99	-	940	24	225	100	730	248	248	940	970	65	-	-	615	1,002	768
Chloride	2,240	-	300	2,000	1,000	220	-	-	2,350	90	1,845	1,100	1,600	485	12,300	280	951	2,000	2,310
NO_3-N	-	5	18	-	-	-	-	-	-	-	-	-	196	10	-	-	-	-	-
NH_3-N	845	141	-	-	-	-	160	100	845	0.2	668	-	-	-	-	-	473	756	1,106
TON	550	152	-	-	-	-	-	-	550	2	101	-	-	-	-	-	288	664	1,416
COD	-	7,130	-	750,000	-	-	3,850	246	-	-	-	35,700	21,120	282	-	-	-	-	-
BOD	32,400	7,050	-	720,000	-	-	1,800	18	33,100	81	5,491	-	-	-	7,330	5.9	14,760	26,940	33,360
TDS	-	9,190	2,000	-	11,254	2,075	-	-	-	-	-	11,254	15,830	1,740	-	-	-	-	-
Specific Conductance	-	-	-	-	-	-	3,000	2,500	-	-	-	-	-	-	-	-	-	-	-

* All analyses in mg/l except pH and specific conductance.

1., 2., 3. From reference 25 (No age of fill specified).
4. From reference 9. (Initial leachate)
5. From reference 9. (3 year old fill)
6. From reference 9. (15 year old fill)
7. From reference 8. (New fill)
8. From reference 8. (Old fill)
9. From reference 26. (Maximum and minimum)
10. From reference 20.
11. From reference 17.
12. From reference 10. (Site A)
13. From reference 10. (Site B)
14. From reference 3. (Maximum and minimum)
15. From reference 22. (Cylinder A, maximum)
16. From reference 22. (Cylinder B, maximum)
17. From reference 22, (Cylinder C, maximum)

a large amount of paper which more than counteracts any moisture from the garbage fraction and other moist materials. However, moisture content increases with age and depth mainly because of infiltration and percolation of rainfall and surface water with time. In Eliassen's landfill studies[7], the moisture content ranged from 18.9 to 34.3 percent. Merz[25] found a moisture retention of 39.5 gallons per cubic yard of refuse from which cans and bottles had been removed. In the California studies[25], rainfall in that area did not penetrate a 7.5-feet thick fill.

The decomposition and stabilization in a landfill is dependent upon many factors including the moisture content. In general, the rate of chemical and biological reactions in a landfill increases with increasing moisture content. In the California study, where a large amount of water was applied to the fill, the settlement was about four times greater than in a similar fill without water addition[25]. Other studies have also indicated that a moderate amount of moisture in the landfill hastened decomposition[27]. Eliassen carried out studies to determine the optimum moisture content for decomposition of landfill material. The procedure involved adding given amounts of moisture to 5-gram dried refuse samples. The results indicated that for fresh landfill material the optimum moisture content for biological decomposition ranges between 50 and 70 percent and for older fills between 30 and 80 percent[7].

Another parameter of considerable significance is temperature. Although a fill may be placed during cold weather, the material is insulated so that heat is not readily transmitted to the atmosphere. In Eliassen's study[7], the reactions in the fills were thermogenic in nature

and the temperatures at the depths of 3 and 7 feet were between 50-70°C; at a depth of 11 feet, the temperature ranged between 25-40°C even though the air temperature was between 20-10°C. These temperatures were in the range between the optimum temperatures for mesophilic (20-40°C) and thermophilic (50-70°C) organisms. Apparently both types of organisms are present to assist in the decomposition of fill material.

Temperature has been monitored in several simulated landfill studies. Fungaroli[11] reported a peak temperature of 68°C within the first week of testing an insulated lysimeter, followed by a slow decline to 60°C and a subsequent rapid decrease to 30°C which remained constant during the remainder of the study. Sixteen days after placement, Carpenter and Setter[3] reported a temperature of 48°C at 3 feet and 55°C at 7 feet; the air temperature was about 24°C. Temperatures recorded after ten months indicated that the temperature of the fill had become stabilized at or near air temperature.

Merz and Stone[19] reported the maximum temperatures of two simulated fills to be 49°C and 42°C and that during the final two years of the study in one fill the temperature ranged from 16°C in the winter to 32°C in the summer; in the other fill, the temperature ranged from 12°C in the winter to 31°C in the summer.

Landfill Design and Operational Criteria

Some attempts have been made to include information on leachate characteristics and behavior in design considerations for sanitary landfills. Hughes[16] has suggested several criteria including a thorough knowledge of the ground water flow system and soil characteristics at

the proposed site. The hydrological and geological suitability of the site could then be ascertained with respect to retardation of ground water pollution. To preclude percolation and leaching, impermeable liners or covers were recommended together with the possible collection and disposal of leachate by an underdrain system. Culham and McHugh[6] have recommended the collection and treatment of leachate from landfills including consideration of filtration, flocculation, and the addition of lime for pH control. The diversion of water from landfill areas was emphasized as an important method for alleviating leachate problems which should be included in design and operational procedures. The pollutional characteristics of leachate can be attenuated or renovated as it moves through the underlying earth material before being discharged to the surface or into the ground water. Emrich[8] recommended one foot of suitable earth material for every foot of refuse. Anderson and Dornbush[30] reported that a pond and a trench located in the downstream direction from the slope of water table improved the quality of water emanating from a refuse disposal area.

Site selection proposed by Cartwright and Sherman[4] included location of landfills in areas where soils of low permeability exist between the bottom of the fill and the highest estimated water table. An interim report[28] by the Department of County of Los Angeles on the development of construction and use criteria for sanitary landfills recommended a geohydrological classification of landfill sites in addition to reduction of leachate problems by diversion of surface runoff in lined channels or storm drains, proper grading and use of relatively impervious surface materials, and construction of suitable barriers to restrict the

infiltration of ground water into the landfill. Hughes[29] discussed the importance of considering the stabilization time in selecting sites, particularly if treatment facilities are planned or if future use of the site is contemplated. Decrease in stabilization time was considered advantageous when leaching is rapid. Permeable cover material and rapid drainage will accelerate leaching and also increase the amount of leachate moving from the fill. The advantage of reducing infiltration into a landfill would be the reduction of quantity and rate of leachate produced. However, reduction of infiltration would extend the "polluting life" of the landfill and if the cover material used had a low permeability, it would tend to force the gases produced during decomposition laterally rather than upward through the surface and thereby cause problems due to the escape of gases at unsuspected locations.

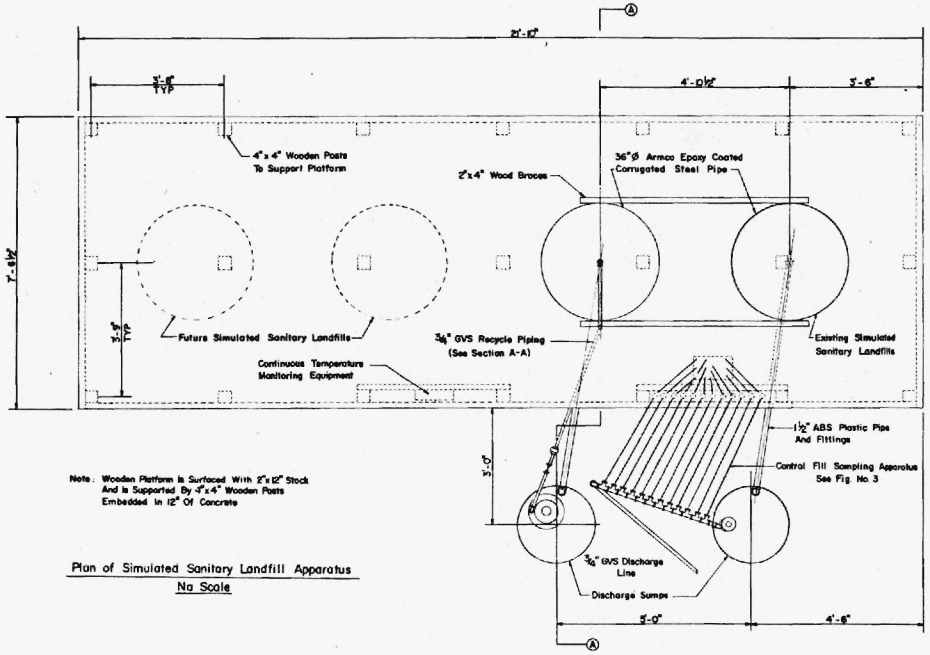
SECTION V

MATERIALS AND METHODS

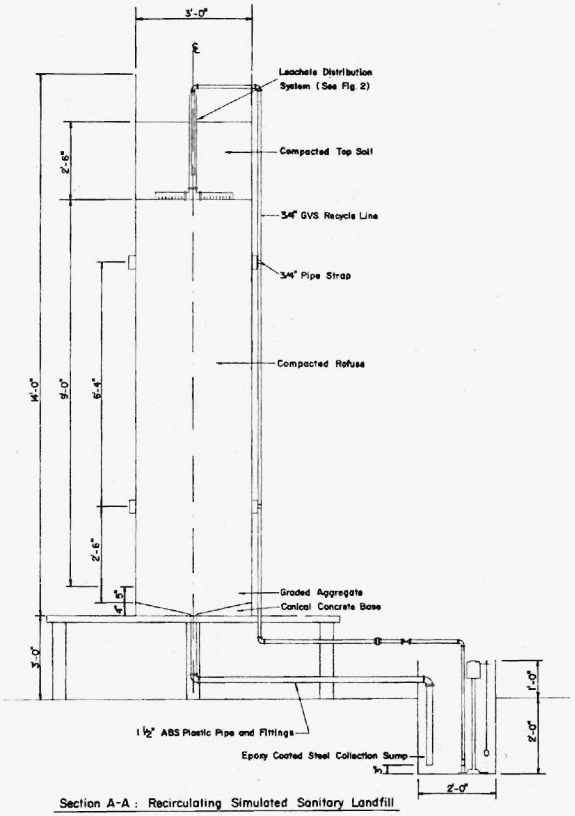
Simulated Landfill Construction

Since the purpose of the research was to develop and study the feasibility of a leachate recycle system to provide leachate treatment and pollution control as well as accelerated rates of biological stabilization within sanitary landfills, two simulated landfills were constructed on the campus of the Georgia Institute of Technology in Atlanta, Georgia. The units were constructed 14-ft. deep by joining sections of 36-in. ARMCO corrugated steel pipe. The pipes were lined with two coats of epoxy, placed on a wooden platform and secured with steel angles bolted around the base of each column. A conical concrete bottom with a 1.5-in. drain was formed in each simulated fill to seal the bottom of the pipe section and allow for the drainage of leachate. Nine inches of graded aggregate were placed in the bottom of each column to prevent clogging by the compacted refuse. The two columns were connected by cross ties and guyed in two directions for stability. The configuration of the landfill structures is shown in Figure 1.

After the units had been erected, all joints and connections were caulked with a sealing compound to prevent air from entering the fill by any means other than some diffusion through the soil cover. Leachate from the simulated landfills was collected in epoxy-lined, 55-gallon drums. A 1.5-in. ABS plastic pipe provided for drainage of the leachate from the base of the simulated fills into the collection sumps. The leachate was removed from the collection system by float operated pumps placed in the collection sumps. To prevent air from entering the fills, the end of each



Plan of Simulated Sanitary Landfill Apparatus
No Scale



Section A-A: Recirculating Simulated Sanitary Landfill
No Scale

Figure 1. Plan of Simulated Sanitary Landfill Apparatus.

drain pipe was completely submerged at all times in the leachate by adjusting the level controls on the sump pumps to cut off two inches above the drain discharge.

Leachate from the non-recirculating control fill was pumped through a proportional sampling device and then to waste. The leachate collected from the recirculating fill was pumped back through a distributor buried between the top of the compacted refuse and the soil cover and allowed to percolate through the refuse (see Figure 1 and Figure 2).

Ten feet of compacted simulated refuse was placed in each of the simulated landfills. The composition indicated in Table 2 was chosen to reflect that of a typical municipal refuse. A total of 2,800 pounds of refuse was coarsely ground with a brush chipper and the dry refuse was mixed in 200-lb. batches. The ground refuse was then hauled manually to the top of the simulated fills and dumped into the columns. The refuse was manually compacted in two 5-ft. lifts to a dry density of about 535 lbs./cu.yd.

Table 2

Composition of Simulated Refuse

Constituent	Dry Weight, Percent
Paper	50.0
Plastic	3.0
Glass	7.0
Garbage	25.0
Rags	5.0
Stone & Sand	5.0
Metal	4.0
Wood	1.0
	100.0

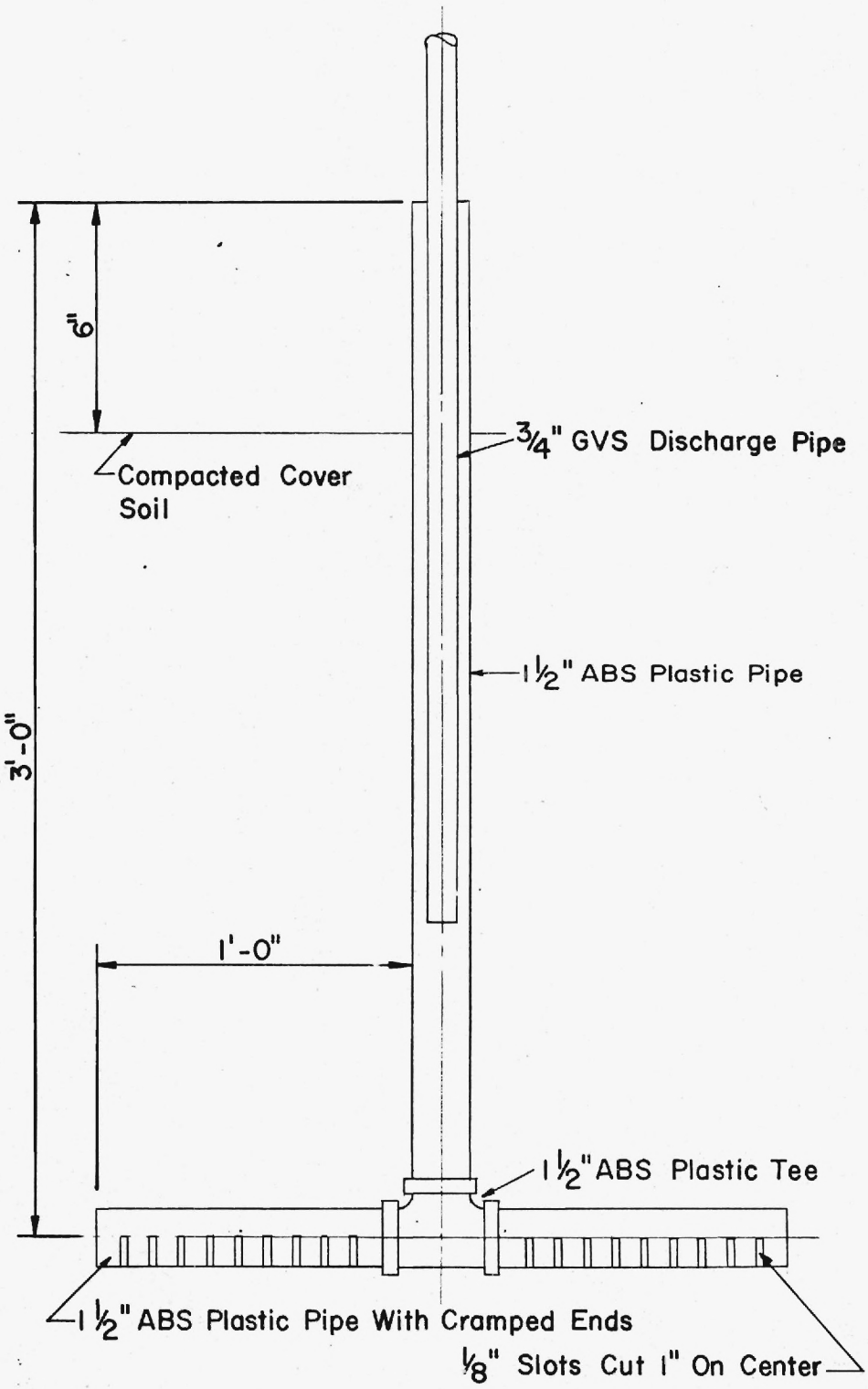


Figure 2. Leachate Distribution System.

A two-week period elapsed before the placement of the soil cover, during which time the two fills, which were capped to exclude rainfall, settled approximately six inches. Due to this settlement, 30-in. of compacted top soil was placed over the refuse to bring the total height of each fill to 12 feet.

To expidite the production of leachate by the fills, 250 gallons of tap water were added after the placement of the compacted soil cover. Based on the moisture holding capacity of synthetic refuse reported in other studies, the addition of 250 gallons of water was considered sufficient to bring the fills up to field capacity. However, since this quantity was applied in a 12-hr. period, some initial short-circuiting resulted. The addition of the water and the added weight of the cover soil also resulted in an initial settlement of 8.5 and 16.5 inches respectively in the control and recirculating fills.

The production of 30 gallons of leachate by both fills after the initial water addition indicated that short-circuiting was occurring. To minimize short-circuiting by rainfall, a blanket of sod was placed over the soil cover to provide better distribution of rainfall across the fill surface and prevent water from flowing down the sides of fills. Short-circuiting of recirculated leachate was minimized by using a gravity flow distributor and capping the ends of the distributor to direct the flow through the center of the fill.

Sampling Procedures

A 24-hr. composite sample was taken from the sump of the recirculating landfill at weekly intervals. An Instrumentation Specialties Company Model 780 automatic water sample collector was used to collect 24,

500-ml. samples which were combined at the end of the sample period. A 1.5-liter aliquot was taken from the composite for analysis. Initially the remainder of the composite was discarded due to the large quantity of leachate collected from the recirculating fill, however residual samples are now being returned to the collection sump.

Samples were obtained from the non-recirculating control fill whenever a sufficient quantity of leachate was produced from rainfall to yield a proportional sample of 1.5 liters. When a sufficient volume of leachate had collected in the base of the control fill, the drain line was uncapped and leachate was allowed to enter the collection sump. The leachate was then pumped from the sump through a proportional sampler as shown in Figure 3 and then to waste. After the leachate had been removed from the sump, the drain line was recapped and the sump and sampler washed down to prevent contamination of the next sample.

The proportional sampling apparatus was constructed by tapping twelve 0.25-in. plastic tubes into the 0.75-in. GVS discharge line from the sump. A 0.25-in. normally closed solenoid valve wired to a stepping circuit actuated by the float control microswitch on the sump pump was placed in each of the 0.25-in. sample lines to allow a portion of the flow to be diverted to a sample bottle when the pump switched to an operational mode. The use of this proportional sampling device allowed representative sampling of the control leachate and also allowed the measurement of leachate production from records of pump operation.

Three sampling ports were installed in each simulated fill to allow refuse samples to be taken periodically and continuous recording instruments to be attached to the fills. Samples of compacted refuse were taken

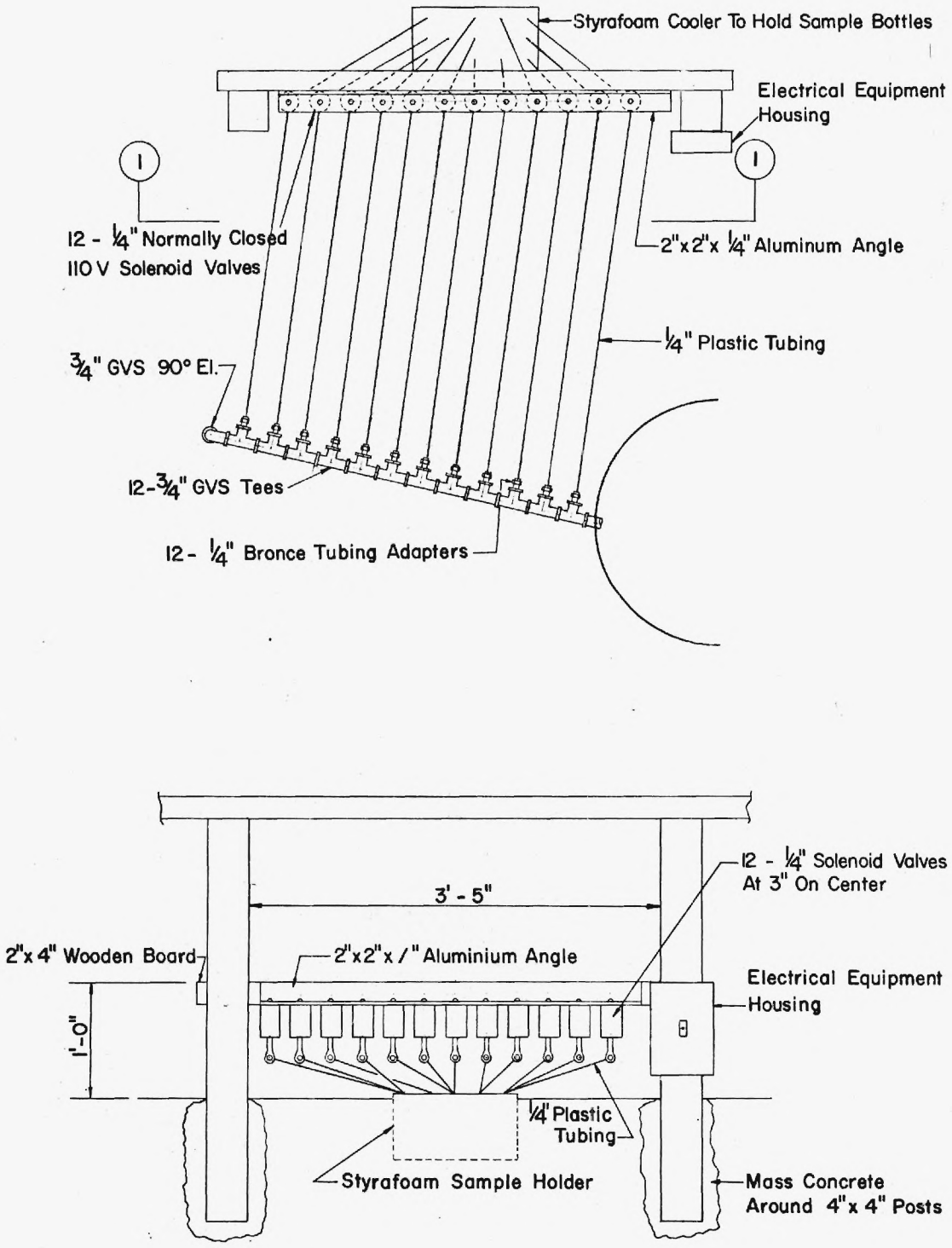


Figure 3. Plan of Control Fill Sampling Apparatus.

from each fill at 3-month intervals with a pointed metal tube to help determine the degree of decomposition that had occurred. The sampling ports were constructed by inserting 0.5-in. GVS pipe lengths through the sides of the fills. The pipe lengths were secured on both sides of the columns by nuts and rubber washers and the connections covered with sealing compound. Two of the ports were capped and a temperature probe was placed in the center sampling opening.

Analytical Methods

Analysis of Simulated Refuse - A two-pound sample of the synthetic refuse was collected and the organic fraction, consisting of paper, plastics, vegetable matter, meat, rags and wood, was finely ground in a Wiley Mill. A portion of this sample was then ground in a micromill and analyzed for carbon, hydrogen and nitrogen with an F&M Model 185 CHN Analyzer. Another portion of the finely ground sample was digested in concentrated sulfuric acid, neutralized, diluted with distilled water and analyzed for Kjeldahl nitrogen with a Technicon Auto Analyzer; potassium, sodium, calcium, and magnesium with a Perkin-Elmer Atomic Absorption Spectrophotometer; and phosphates using the procedure outlined in "Standard Methods".

The refuse taken from the simulated landfills was analyzed for carbon, hydrogen and nitrogen using the CHN analyzer, and moisture content and volatile solids using the procedures given in "Standard Methods".

Analysis of Soil Characteristics - Two plexiglass columns were each filled with 2,000 grams of soil similar to that to be used as cover in the simulated landfill studies. The soil was leached with demineralized water to determine the potential contribution of various substances in the cover soil to the fill leachate. The leachate from one soil column was recirculated

back through the column and the leachate from the second column was discharged to waste. This allowed the total quantities of iron, calcium, magnesium, manganese, sodium, ammonia nitrogen, total nitrogen and total organic carbon leached from the soil to be determined and also indicated to some degree the ion exchange capacity of the soil. The soil leachate was analyzed for sodium, calcium, magnesium, manganese and iron with an Atomic Absorption Spectrophotometer; total organic carbon with a Beckman Total Carbon Analyzer; and nitrogen with a Technicon Auto-Analyzer.

Analysis of Leachate Samples - The fill leachate samples were analyzed for 5-day biochemical oxygen demand (BOD_5), total organic carbon (TOC), chemical oxygen demand (COD), total suspended solids (TSS), volatile suspended solids (VSS), total solids (TS), alkalinity, acidity, total hardness, total and ammonia nitrogen, nitrates, phosphates, calcium, magnesium, manganese, sodium, iron, chlorides, sulfates, pH and volatile acids. Since it was the purpose of this research to determine the effects of leachate recirculation on landfill stabilization, the preceeding analyses were considered adequate to reflect the process of stabilization in the fill and also demonstrate the possible accumulation of any pollutional substances.

Nitrates and chlorides were measured with an Orion Specific Ion Electrode and calcium, magnesium, manganese, sodium, iron and sulfate were measured with an atomic absorption spectrophotometer. Phosphates and hardness were determined by Hach Kit methods, and total and ammonia nitrogen were determined with an autoanalyzer. The remaining analyses were performed according to "Standard Methods".

SECTION VI

PRESENTATION OF THE DATA

Preliminary results of the analyses performed on the simulated refuse, cover soil and leachate samples are presented in this section. The time scales used in this presentation (time since placement of refuse and time since leachate production began) are related in that operating procedures allowed for the production of leachate 40 days after the placement of the simulated refuse.

Refuse Composition

Analysis of the organic portion of the refuse indicated an initial composition as shown in Table 3. The primary constituents of the refuse were carbon, hydrogen and oxygen with nitrogen, potassium, sodium and phosphate occurring in trace amounts.

Table 3

Initial Chemical Composition of the Organic Fraction of the Simulated Refuse

Refuse Constituent	Weight Percent
Carbon	47.20
Hydrogen	5.15
Oxygen	46.73
Nitrogen	0.65
Potassium	0.12
Sodium	0.12
Phosphate	0.03
	100.00
Volatile Solids	98.62

The comparison of the initial composition of the organic fraction of the refuse (paper, plastics, vegetable matter, meat, rags and wood) with the composition of samples taken from the two simulated fills 11 weeks after the placement of the refuse (see Table 4) indicated that the refuse in both fills had undergone reductions in organic carbon and volatile solids and that the moisture content of both fills was essentially similar.

Cover Soil Characteristics

Figure 4 and Table 5 indicate the results of the leaching column tests with the cover soil. Calcium, magnesium, and sodium were the only materials leached from the cover soil in measurable quantities. As was expected, the concentrations of iron in the leachate was very low and somewhat erratic. The concentrations of calcium, magnesium and sodium were initially high but dropped sharply during the first 30 hours of leaching.

Graphical intergration of the mass flow curves of each element indicated that the quantity of cover soil on each fill would produce only a negligible amount of each of the elements. Accordingly, the 2.5 feet of cover soil placed on the top of each fill should leach 58.9 grams of calcium, 11.9 grams of magnesium, and 1.27 grams of sodium in 144 hours of continuous leaching.

The equilibrium concentrations reached during the recirculation study indicated that the cover soil was a rather poor ion exchange medium for the indicated constituents. The highest affinity demonstrated by the soil was for calcium with sodium being held less than calcium but more than magnesium.

Table 4

Comparison of the Initial Composition of the Organic Fraction of the Refuse with the Composition of Samples Taken from the Simulated Fills 11 Weeks After the Placement of the Refuse

Refuse Constituent	Weight Percent		
	Initial	After 11 Weeks	
		Control Landfill	Recirculating Landfill
Carbon	47.20	42.50	40.50
Hydrogen	5.15	4.87	4.58
Oxygen	46.73	51.16	54.5
Moisture	-	73.70	76.20
Volatile Solids	98.62	94.80	60.60

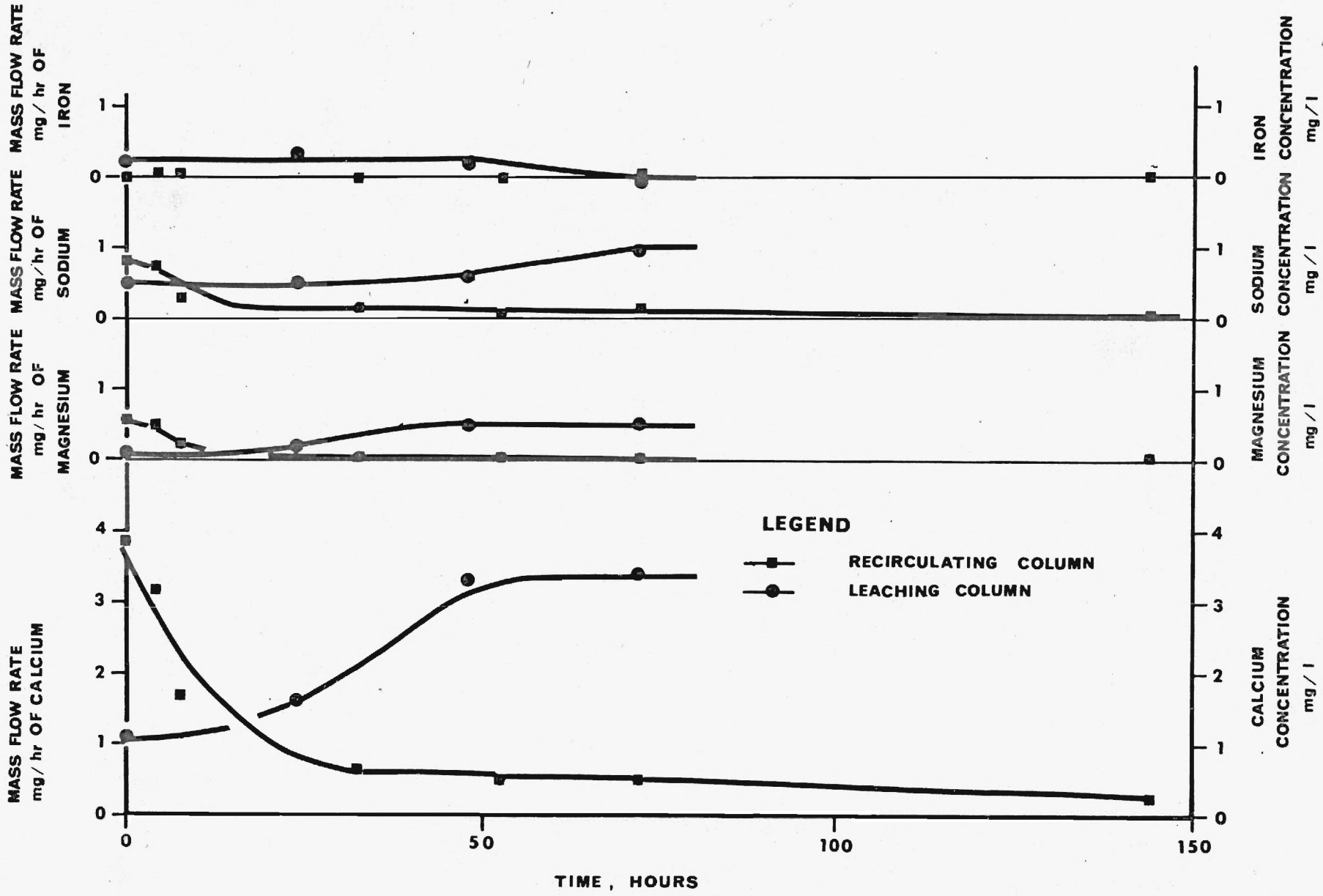


FIGURE NO 4 : RESULTS OF COVER SOIL LEACHING STUDY

Table 5

Results of Cover Soil Leaching Experiments

Time, hr.	Mass Flow Rate, mg/hr				Time, hr.	Concentration, mg/l			
	Ca	Mg	Na	Fe		Ca	Mg	Na	Fe
0	3.86	0.59	0.80	0	0	1.1	0.1	0.5	0.2
4	3.19	0.50	0.76	0.04	24	1.6	0.2	0.5	0.3
7.5	1.68	0.21	0.29	0.04	48	3.3	0.5	0.6	0.2
32.5	0.63	0.04	0.17	0	72	3.4	0.5	1.0	0
52.5	0.50	0.04	0.08	0					
72	0.50	0.04	0.17	0.04					
144	0.25	0.04	0.04	-					
Total Mass Leached $\frac{gm}{gm} \times (10^6)$	48.9	4.95	1.06	-	Equilibrium Value mg/l	3.4	0.5	1.0	-

Landfill Temperature

Temperatures in the simulated landfills followed a temperature variation which corresponded to the daily ambient temperature fluctuations as illustrated in Figure 5 for the initial stages of the study. The maximum temperatures (July) reached were 32°C in the control fill and 31°C in the recirculating fill; the minimum temperatures (December) were 5°C and 4°C respectively. The temperature variations in the control fill were more dramatic than in the recirculating fill where temperature was moderated by the recycled leachate. Installation of insulation will provide for temperature control of large fluctuations during extreme temperature periods.

Landfill Settlement

The cumulative surface settlement of both fills is shown in Table 6. As previously mentioned, both fills experienced settlement due to the placement of cover soil and the initial addition of water to the fills. This initial settlement was not included in the settlement data, and the cumulative settlement was calculated from the fill heights after the addition of cover soil and water.

Leachate Analysis

Cumulative precipitation intercepted by both fills is shown in Table 7. The total precipitation intercepted by each of the fills was 101.98 inches including the water equivalent to 56.6 inches which was initially added to saturate the fills. Total leachate production from the control fill (see Table 8) was 11.416 inches (49.50 gals.) including the equivalent 6.804 inches (30 gals.) which were produced when the fills were initially saturated. After allowing for the moisture required to

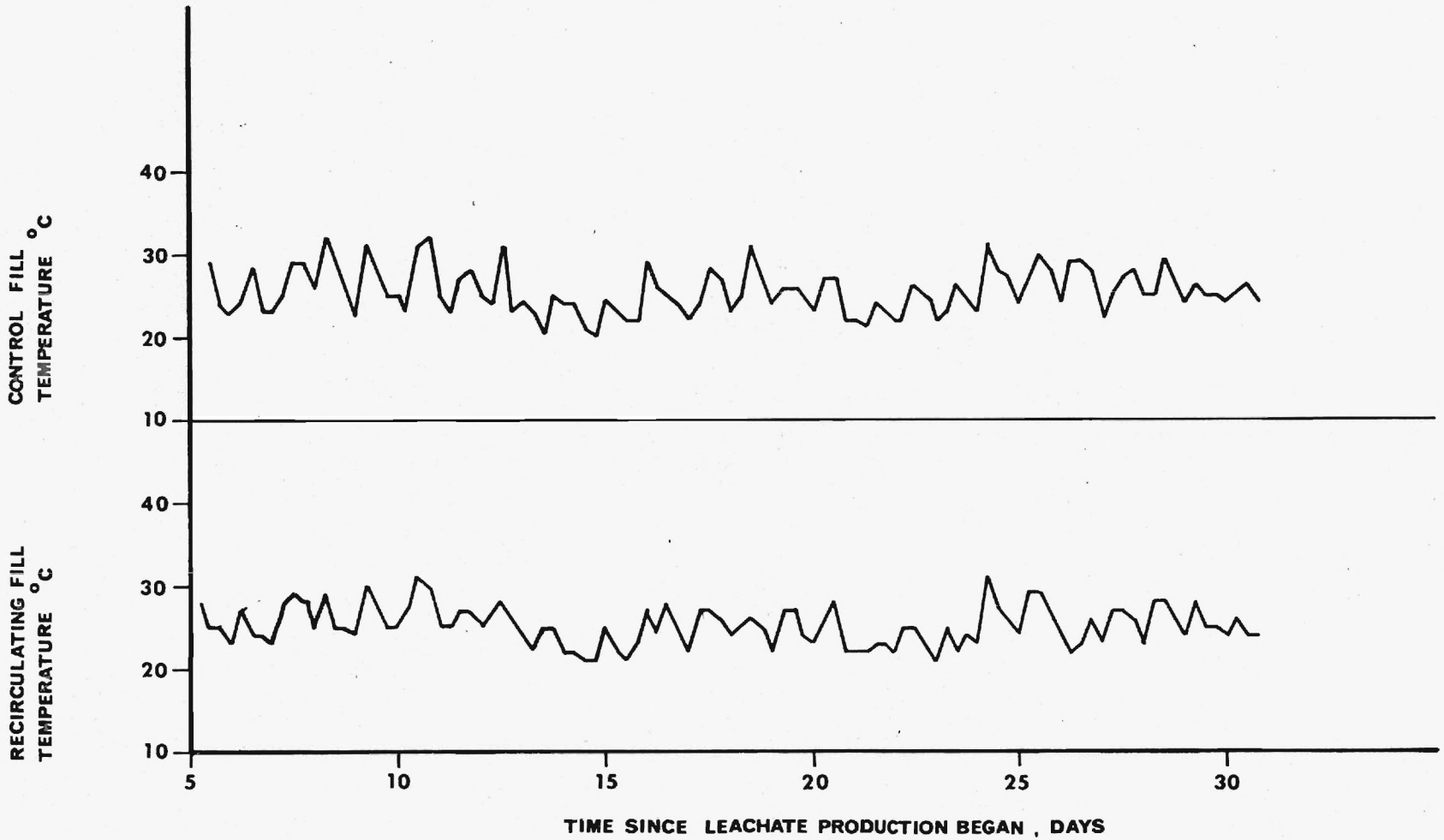


FIGURE NO 5 : INTERNAL TEMPERATURE VARIATION OF THE SIMULATED LANDFILLS

Table 6

Cumulative Surface Settlement
of the Simulated Landfills

Time Since Placement of Refuse days	Cumulative Surface Settlement, ft.	
	Recirculating Landfill	Control Landfill
40	0	0
42	1.0	.504
46	1.21	.790
50	1.21	.790
53	1.21	.790
57	1.22	.780
60	1.28	.780
64	-	.880
67	1.44	.880
71	1.48	.950
78	1.48	.950
90	1.48	.980
122	1.50	.990
134	1.50	1.010
157	1.50	1.019
180	1.50	1.027
200	1.50	1.032

Table 7

Daily and Cumulative Precipitation
Received by Both Landfills Since Refuse was Placed

Time Since Placement of Refuse days	Precipitation, in.	Cumulative Precipitation, in.
0	0	0
5*	0.37	0.37
21	0.68	1.05
27	0.23	1.28
29	1.22	2.50
32	0.37	2.87
33**	56.60	59.47
36	0.98	60.45
38	0.18	60.64
40	3.07	63.71
45	1.11	64.82
46	0.98	65.80
47	1.72	67.52
61	1.02	74.54
66	3.70	78.24
70	1.23	79.47
77	1.90	81.37
90	3.50	84.87
124	0.74	85.61
134	0.86	86.47
136	1.84	88.31
165	1.85	90.16
169	4.06	94.22
180	1.23	95.45
194	1.84	97.29
197	3.69	101.98

*Fills were capped until 5 days after refuse was placed.
**250 gals. of water were added to each fill to bring them to field capacity.

Note: Rainfall was measured daily.

Table 8

Cumulative Leachate Production
By The Control Landfill*

Time Since Placement of Refuse, days	Leachate Production, in.	Cumulative Leachate Production, in.
0	0	0
33	6.804	6.804
47	2.040	8.844
57	0.034	8.878
65	0.454	9.332
72	0.566	9.898
81	.198	10.096
116	.294	10.390
125	.180	10.570
153	.239	10.809
173	.216	11.025
189	.210	11.235
197	.181	11.416

*Total leachate production by the control fill was 49.50 gals. including the 30 gals. initially obtained by addition of water to reach field capacity. Leachate was measured either when enough had accumulated in the control fill to provide a proportional sample of 1.5 liters or two days after rainfall.

saturate the soil cover, the refuse had a moisture holding capacity of 1.59 inches of water per cubic yard of refuse.

The initial leachate samples taken from the two fills were dark green in color and had a rotten garbage odor. The samples taken from the recirculating fill later lost this characteristic color and odor, whereas the control fill samples became grayish-green in color and acquired a putrid odor similar to that of the short chained organic acids. Although the leachate from both initially fills had a strong odor, no odors could be detected at the surface or around the landfill columns.

The concentrations of extracted materials in the leachate obtained from the simulated landfills are tabulated in Tables 9 and 10 and displayed graphically in Figures 6 through 11.

Table 9

Concentrations of Extracted Materials in Leachates Obtained from Control Landfill

Time Since Leachate Production Began, days	0	14	24	32	39	48	81	116	125	153	173	189	197
COD, mg/l	4,320	9,150	10,380	10,260	12,000	11,700	9,200	10,100	11,700	12,200	12,300	14,400	15,600
BOD_5, mg/l	2,500	5,000	9,200	6,330	11,000	8,200	8,800	9,600	8,700	11,100	9,200	12,000	9,300
TOC, mg/l	1,230	1,910	2,622	2,622	2,802	2,835	2,864	2,259	2,418	2,680	2,696	3,049	3,409
TSS, mg/l	125	34	59	61	47	213	270	640	550	292	470	360	---
VSS, mg/l	45	20	47	52	37.6	93	160	332	314	182	268	210	---
TS, mg/l	2,442	5,819	6,323	8,300	8,736	6,789	5,530	7,250	7,358	7,620	7,875	8,320	4,840
Total Alkalinity, mg/l as $CaCO_3$	558	1,610	1,640	1,920	2,280	2,110	2,420	2,650	2,120	2,350	2,100	2,482	1,760
Total Acidity, mg/l as $CaCO_3$	690	1,100	1,350	1,400	1,780	2,170	1,836	1,390	2,090	2,230	2,780	2,865	3,260
pH	5.2	5.6	5.3	5.3	5.3	5.3	5.7	5.3	5.2	5.3	5.1	5.2	5.1
Total Hardness, mg/l as $CaCO_3$	450	1,400	1,850	1,810	1,940	1,754	1,410	1,429	1,694	2,232	2,354	2,306	2,449
Acetic Acid, mg/l	500	2,111	2,360	2,664	3,666	3,268	2,789	3,285	2,590	3,280	3,440	3,393	3,550
Propionic Acid, mg/l	369	1,595	1,834	2,038	2,313	2,108	1,875	2,625	2,110	2,290	2,190	2,400	2,214
Butyric Acid, mg/l	110	965	1,075	1,050	1,280	1,164	1,000	1,203	1,424	1,195	1,215	1,350	1,750
Valeric Acid, mg/l	0	425	575	625	535	612	643	893	656	708	652	730	801
Phosphate, mg/l $PO_4^{\equiv}$	26	3.0	5.0	7.8	2.8	2.9	3.3	4.2	3.4	2.8	1.7	1.6	1.5
Organic Nitrogen, mg/l as N	56	47	61.4	62	75	48	40	177	64	6	20	12	43
Ammonia Nitrogen, mg/l as N	56	150	167.6	187	185	192	148	103	130	260	214	218	264
Nitrate Nitrogen, mg/l NO_3^-	13.3	32	89	84	115	15.0	---	9.5	12	---	---	---	---
Chloride, mg/l	322	385	109.8	105.1	97.9	340	---	170	240	210	208	312	308
Sulfate, mg/l $SO_4^{=}$	84	126	108	81	156	17	2	7	1	16	---	---	---
Calcium, mg/l Ca	125	430	470	590	750	545	430	375	420	600	578	565	545
Magnesium, mg/l Mg	26	71.8	67	75	68	64	52	49	53	80	85	85	75
Manganese, mg/l Mn	3	10	5	6.2	8.8	8.5	10	7.5	10	16	14	15	16
Sodium, mg/l Na	63.8	125	132	132	143	150	180	118	135	155	154	155	148
Iron, mg/l Fe	9	21	70	30	95	65	60	155	230	200	300	290	420

Table 10

Concentrations of Extracted Materials in Leachates Obtained from Recirculating Landfill

Time Since Leachate Production Began, days	0	10	18	24	31	39	48	58	67	96	111	126	140	161	189	197
COD, mg/l	4,280	9,288	8,870	9,080	8,111	7,700	8,140	9,580	10,400	10,025	10,500	10,500	10,350	8,890	5,810	4,270
BOD_5, mg/l	2,750	5,200	6,900	6,800	4,300	5,400	6,202	6,400	6,380	7,200	8,700	8,500	10,100	9,405	6,650	3,500
TOC, mg/l	2,130	1,120	2,260	2,040	2,394	1,818	2,665	2,000	2,675	2,798	1,990	1,979	1,952	1,542	1,280	1,067
TSS, mg/l	93	13.6	12	36.5	70.5	25	37.0	120	301	143	222	258	385	187	232	220
VSS, mg/l	22.5	---	9	27.5	45	18.8	16.9	70	161	78	158	142	188	118	156	116
TS, mg/l	2,349	4,329	4,552	5,023	5,400	4,728	4,941	5,250	5,440	5,980	5,830	6,918	6,106	5,336	4,090	3,987
Total Alkalinity, mg/l as $CaCO_3$	302	700	865	1,080	1,200	1,370	1,525	1,438	1,035	1,900	2,350	1,640	1,670	1,640	1,550	1,342
Total Acidity, mg/l as $CaCO_3$	554	1,900	1,540	1,350	1,000	1,390	1,265	1,530	1,765	1,798	1,730	1,830	1,700	1,630	500	333
pH	5.05	4.8	5.0	5.1	5.3	5.4	5.3	5.3	5.1	5.4	5.5	5.3	5.3	5.2	6.3	6.6
Total Hardness, mg/l as $CaCO_3$	370	895	880	1,010	890	1,040	1,222	1,483	1,532	1,701	1,987	1,495	2,296	1,948	1,469	1,146
Acetic Acid, mg/l	1,638	556	2,000	1,843	1,475	1,583	1,795	2,146	2,438	2,742	2,438	2,470	2,380	1,877	2,925	608
Propionic Acid, mg/l	960	394	1,242	1,467	1,554	1,594	1,580	1,752	1,953	2,203	1,953	1,865	2,020	1,472	1,995	714
Butyric Acid, mg/l	1,300	235	1,235	1,163	1,375	1,250	1,200	1,198	1,094	1,156	1,047	1,124	937	735	665	286
Valeric Acid, mg/l	500	735	50	833	688	670	714	800	858	857	786	842	625	556	585	276
Phosphate, mg/l $PO_4^{\equiv}$	22	1.5	2.1	0.65	0.81	0.67	0.82	0.85	0.98	0.65	0.38	0.50	0.39	0.82	0.47	0.26
Organic Nitrogen, mg/l as N	20	0	30	405	37.5	39.5	41	30	39	62	92	28	7	3	4	0
Ammonia Nitrogen, mg/l as N	70	68	113.5	86.5	77.5	76.5	64	69	81	84	80	71	135	126	80	62
Nitrate Nitrogen, mg/l NO_3^-	6.2	71.4	56.6	76.6	48	49	11.0	11.5	12.0	16.0	21.0	14.0	---	---	---	---
Chloride, mg/l	210	210	248	94.5	91	115	220	164	176	140	188	170	210	236	300	270
Sulfate, mg/l $SO_4^{=}$	102	138	81	51	30	12	11	<1	12	2	1	3	---	---	---	---
Calcium, mg/l Ca	60	315	350	435	420	430	420	415	440	500	550	385	600	475	400	340
Magnesium, mg/l Mg	16.5	59	53.5	62.5	56	56	50	50	53	55	62	44	70	60	50	45
Manganese, mg/l Mn	4	30	50	65	62	62	75	75	80	80	85	60	93	80	59	50
Sodium, mg/l Na	61.5	109	81.4	91.4	85	84	95	85	88	90	98	70	84	75	61	59
Iron, mg/l Fe	4.4	19.5	19	80	43	110	25	35	40	45	110	150	150	210	90	13

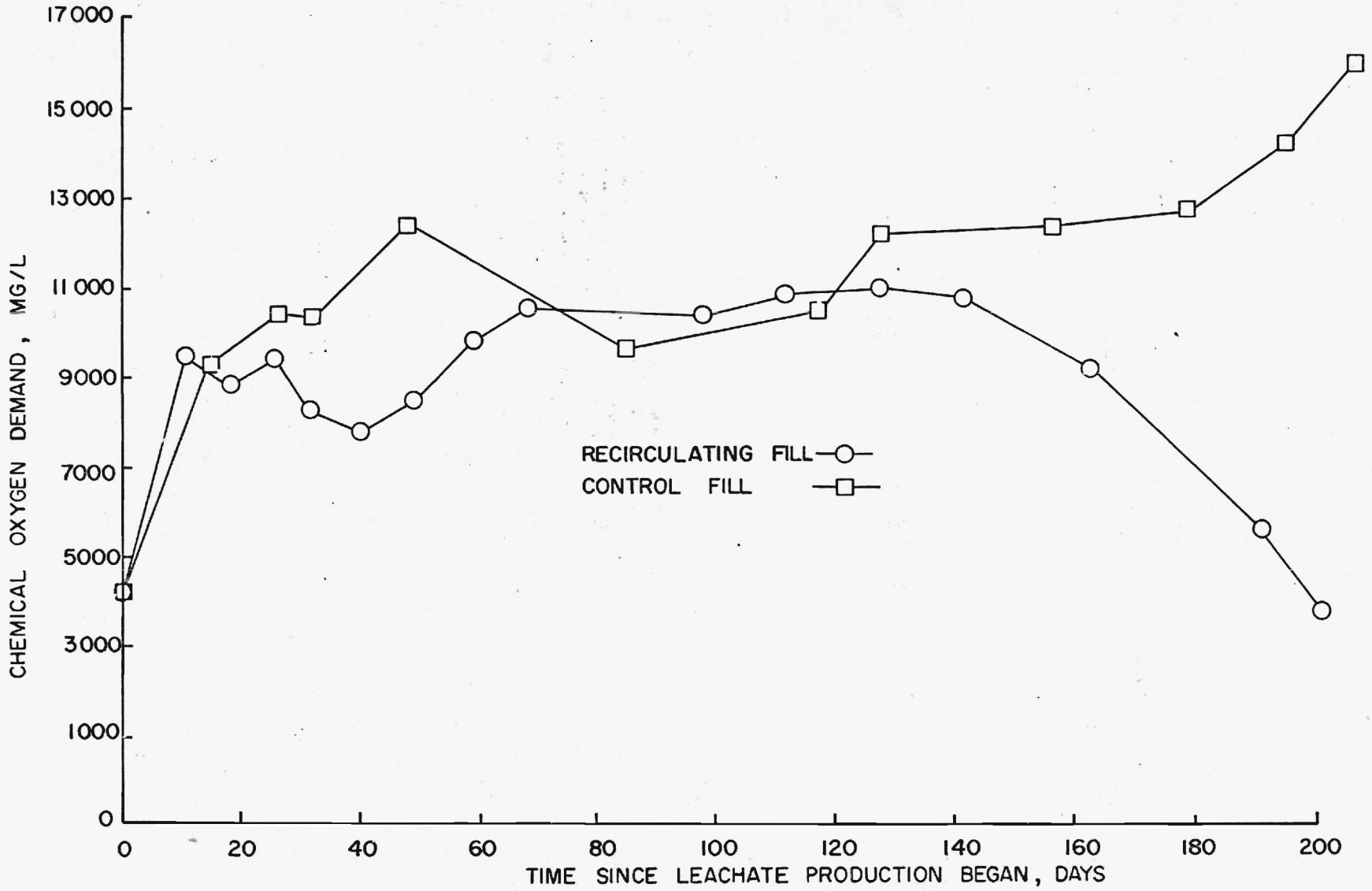


FIGURE NO. 6 : CHEMICAL OXYGEN DEMAND OF LEACHATE FROM RECIRCULATING AND CONTROL FILLS

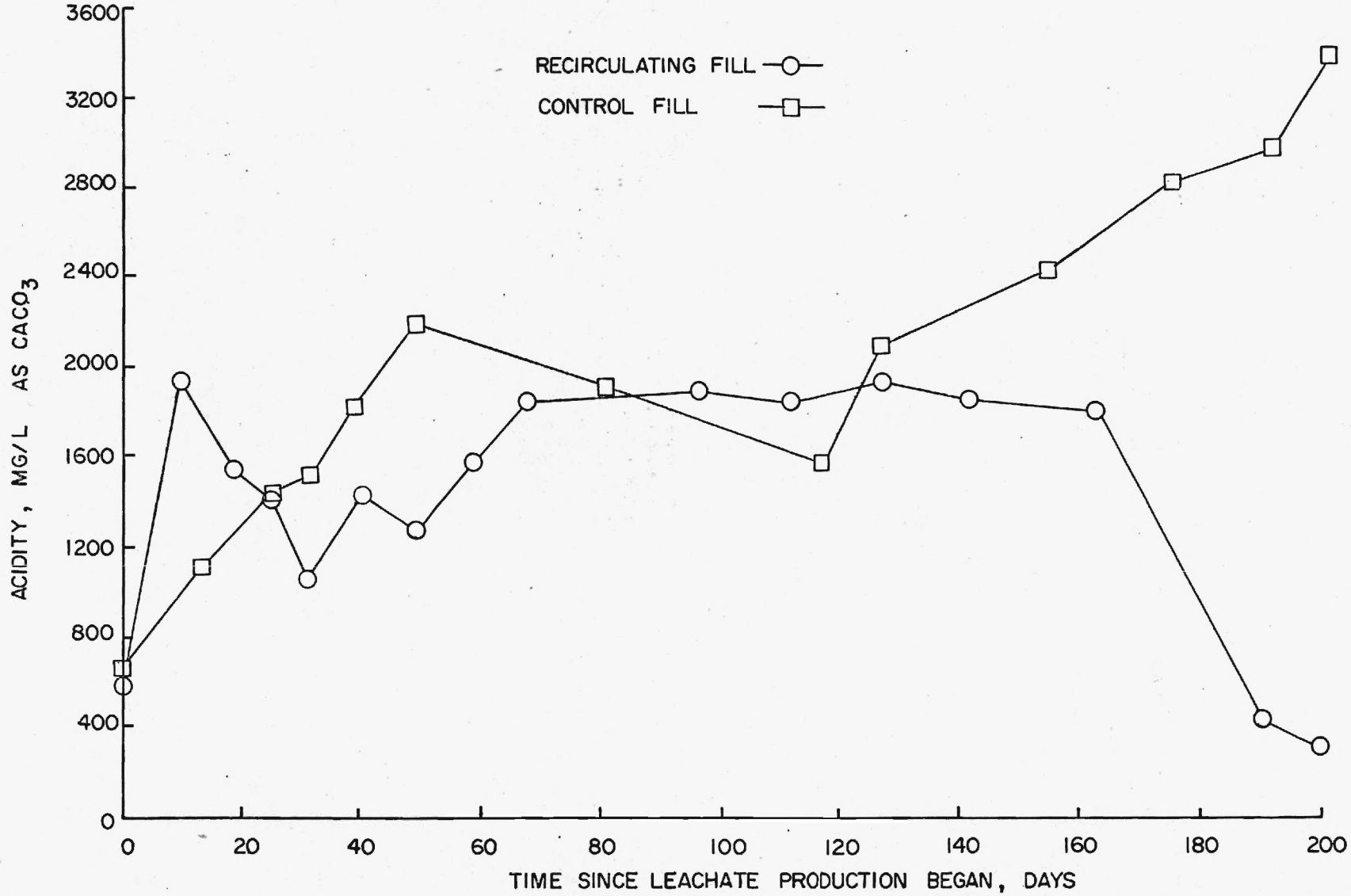


FIGURE NO. 7 : LEACHATE ACIDITY OF RECIRCULATING AND CONTROL FILLS

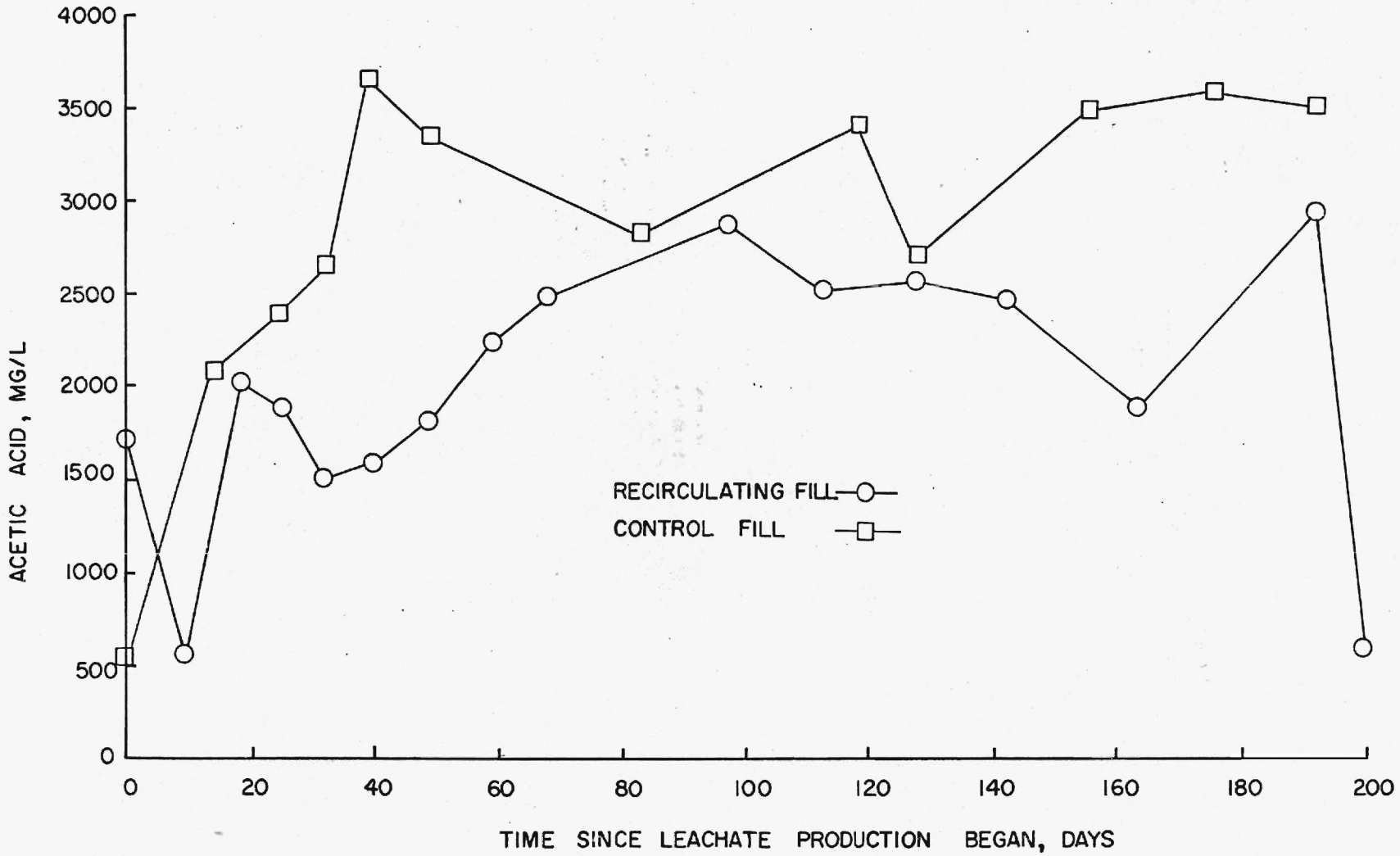


FIGURE NO. 8 : CONCENTRATION OF THE ACETIC ACID IN LEACHATE

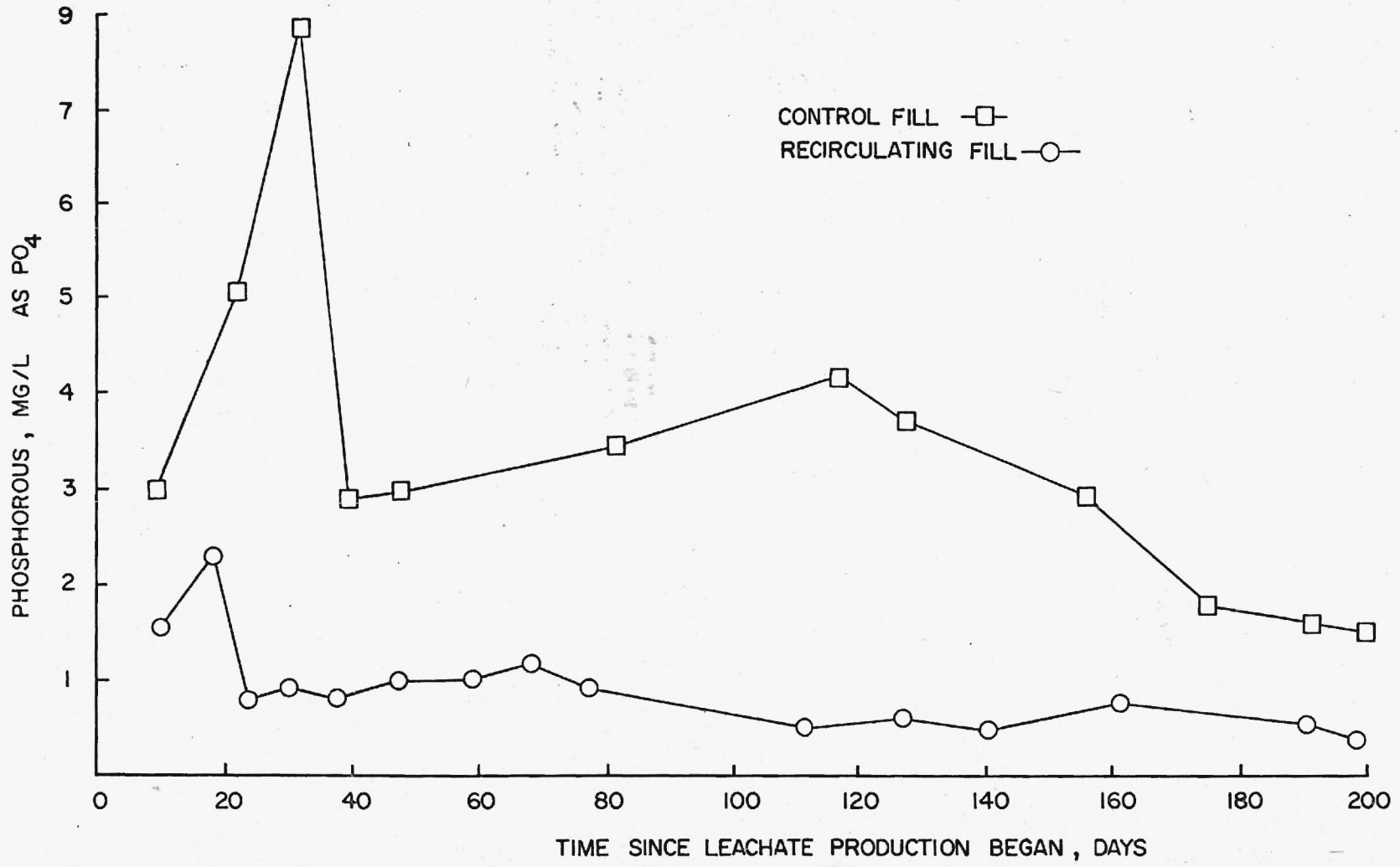


FIGURE NO 9 : CONCENTRATION OF PHOSPHATE IN LEACHATE

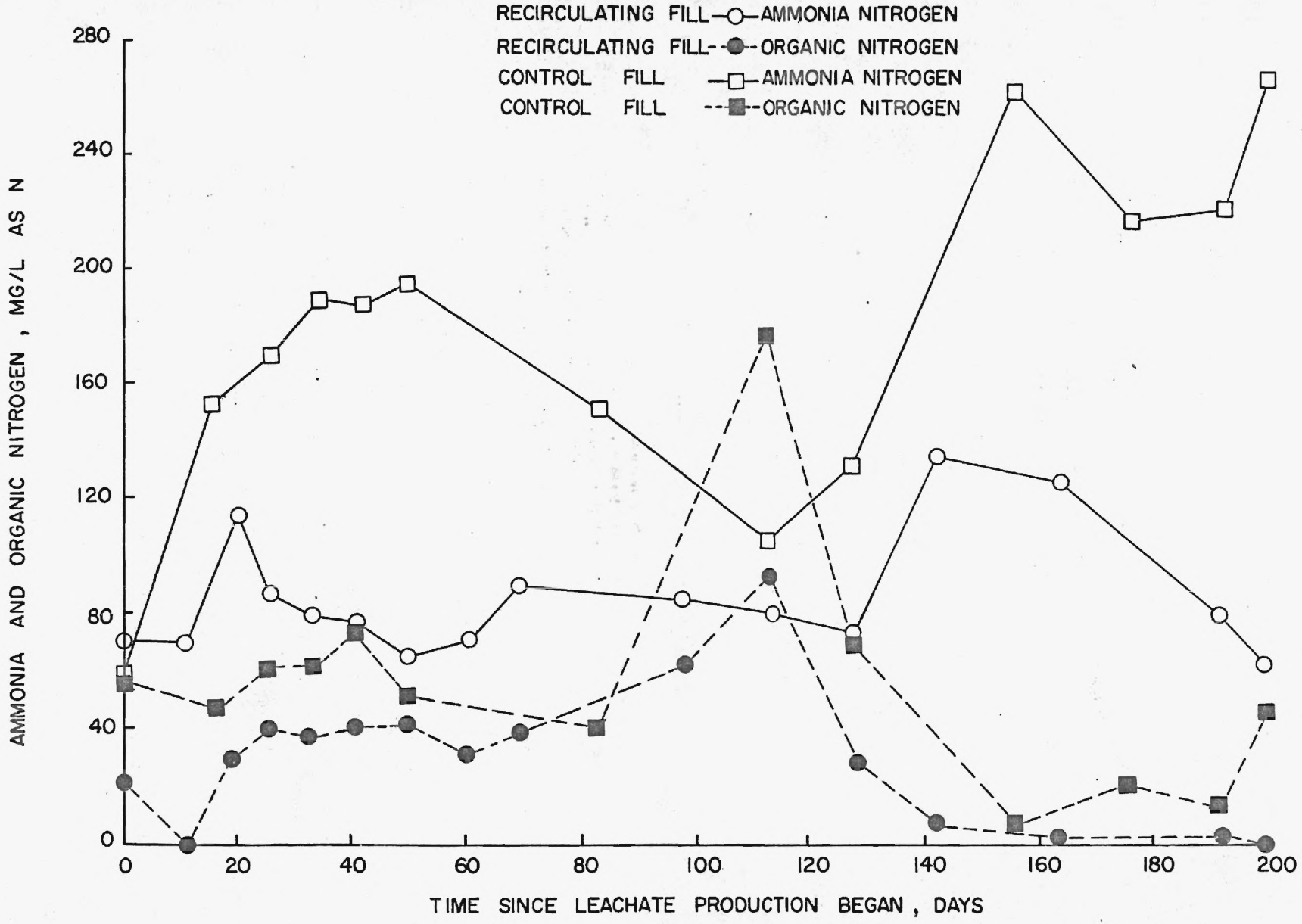


FIGURE NO. 10 : CONCENTRATION OF ORGANIC AND AMMONIA NITROGEN IN LEACHATE

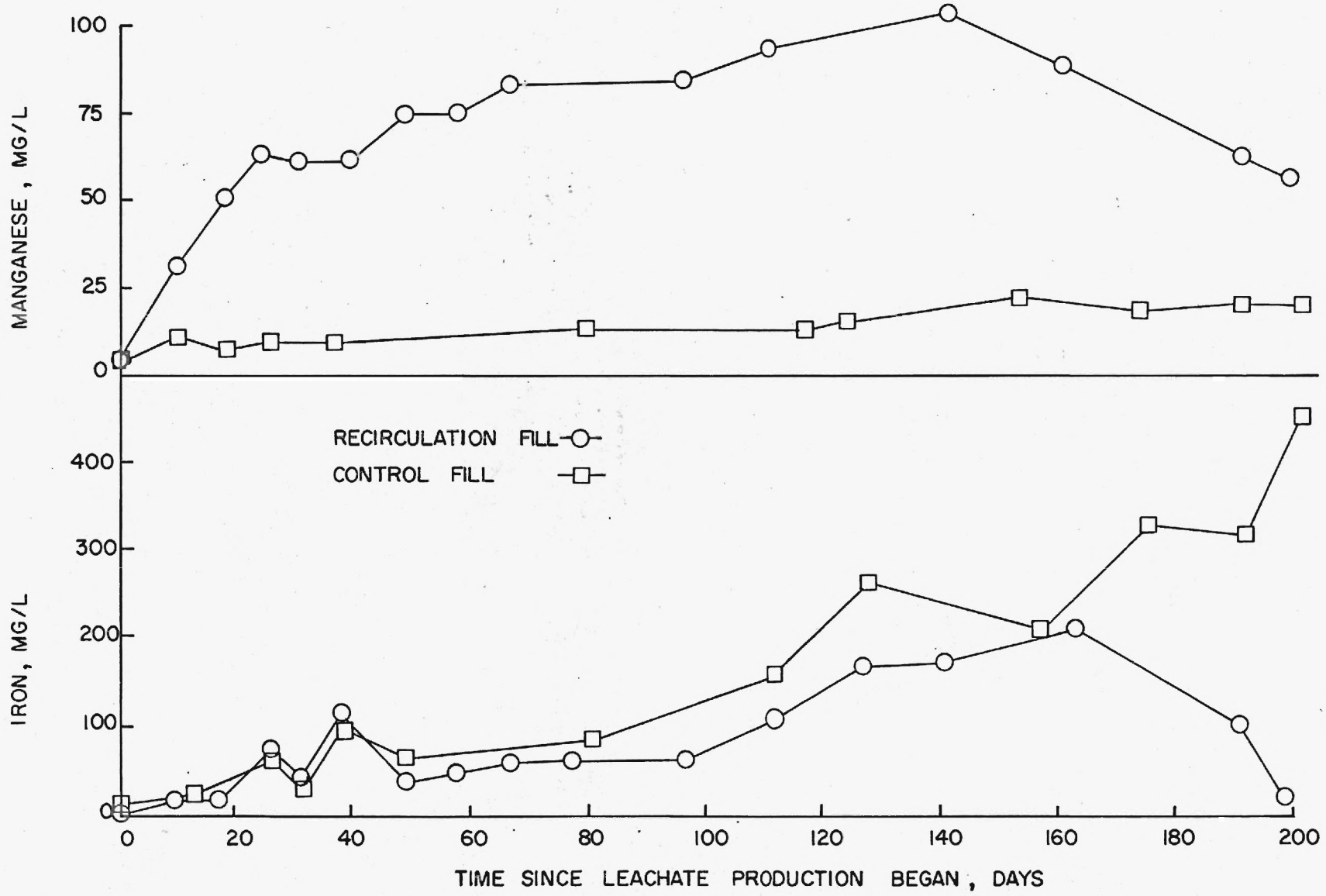


FIGURE NO. 11 : CONCENTRATION OF IRON AND MANGANESE IN LEACHATE

SECTION VII

DISCUSSION

The sanitary landfill method of solid waste disposal depends upon anaerobic biological activity to stabilize the decomposable fractions of refuse. The anaerobic process generally proceeds through two phases with one group of organisms breaking down the larger organic molecules into short chained organic acids (acid fermentation), and the short chained acids being subsequently converted to carbon dioxide and methane by another group of organisms (methane formation).

The methane formation phase is generally considered the rate controlling step in the anaerobic process since it proceeds at a much slower rate and requires a higher degree of environmental control than acid fermentation. The greatest majority of methane forming organisms require strictly anaerobic conditions and a near neutral pH. If acid production exceeds the rate of methane formation to an extent greater than the capacity of the system to buffer the acids produced, the pH will drop below the level at which the methane producers can survive and the methane forming phase of the process will cease to function efficiently. In a properly operating anaerobic system, however, the production of volatile acids will rise initially to a peak value and then decrease. The pH and alkalinity of the system will decrease during the increase in volatile acids and will then rise steadily while the volatile acids diminish.

This preliminary study of the effect of leachate recycle on landfill stabilization was carried on for 197 days. The significance of the trends observed in leachate quality and landfill settlement are discussed as they relate to landfill stabilization and environmental pollution.

Effect of Recirculation on Landfill Stabilization

The rate of surface settlement in the recirculating landfill was much greater than for the control fill. The increased surface settlement was probably attributable to an increased rate of biological stabilization and mechanical settling due to the recirculation of leachate through the test fill.

The cumulative surface settlement of the recirculating fill presented in Table 6 was much greater and occurred at a faster rate than in the control fill. The total surface settlement for the control fill was 1.032 feet while the recirculating fill settled 1.50 feet during the same period.

That a more active biological population was present in the recirculating fill than in the control fill was evident from analysis of the trends observed for volatile acids, pH, alkalinity, sulfate, manganese, and iron (see Tables 9 and 10). The volatile acid concentrations in the recirculated leachate increased during the first few weeks, but then decreased dramatically at the end of this study phase. Conversely, the volatile acid production in the control fill increased steadily. The pH of the recirculated leachate decreased initially and then increased at the end of the study phase whereas the pH of the control remained stable at about 5.2 to 5.3. Similarly, the alkalinity of the recirculated leachate remained lower than the alkalinity of the control but increased with changes in pH and volatile acids.

The trends observed for sulfates, manganese and iron indicated that the reducing atmosphere in the recirculating fill was initially greater than in the control. The sulfate concentration in both leachates was initially high but decreased steadily with reduction of the sulfate to sulfide and its possible precipitation and/or removal in the recirculating fill. The manganese concentration in the recirculated leachate increased steadily to an equilibrium value while the concentrations in the control remained lower which possibly indicated that insoluable manganese was being reduced to the soluable manganous form to a greater extent in the recirculating fill. The concentration of iron found in the recirculated leachate was approximately the same as found in the control and somewhat contributed to by some corrosion noticed in the units. However, a slightly higher concentration in the recirculated leachate may have indicated that ferric iron was being reduced to soluble ferrous iron to a slightly greater extent in the recirculating fill. When these trends were examined in the context of anaerobic processes, they suggested that a more active anaerobic population was initially developed in the recirculating landfill than in the control.

A comparison of the initial refuse composition with the composition of samples taken from the fills after 11 weeks indicated that stabilization of the organic portion of the refuse had proceeded further in the recirculating fill than in the control. After 11 weeks, the refuse in the recirculating fill had experienced a 6.7% reduction in organic carbon, a 0.23% reduction in organic nitrogen and a 38% reduction in volatile solids. The control fill refuse experienced only a 4.6% reduction in organic carbon, no measurable overall decrease in nitrogen and a 3.8% reduction in volatile solids. This comparison was even more dramatic later and indicated the probable presence of a more active anaerobic biological population in the recirculating fill than in the control.

It also implied that the greater settlement initially observed in the recirculating fill was due in part to an increased rate of biological stabilization.

The cumulative settlement data presented in Table 6 indicated that the settlement which occurred during the first six days was due to physical compaction by the water applied and that biological stabilization was primarily responsible for settlement thereafter. During the first 6 days, surface settlement of the recirculating and control fills was 1.21 and 0.790 feet respectively. Rainfall during the same period was 5.161 inches (0.86 inches/day) which easily accounted for the control fill settlement and when superimposed on the recirculation rate explained the settlement of the recirculating fill. Both fills remained at the height observed on the sixth day for some time, however, the recirculating fill began settling again 7 days earlier than the control and proceeded at a more rapid rate. The period of no settlement after the sixth day indicated that the initial settlement observed was due to mechanical compaction. The initiation of settlement after the period of no settlement indicated that the secondary settling was probably due to biological activity and also that biological activity was established sooner in the recirculating fill.

Effect of Recirculation on Leachate Quality

The recirculation of leachate through a simulated sanitary landfill resulted in better nutrient transport and stabler conditions within the fill and the development of an active anaerobic biological population. The conditions produced within the recirculating fill resulted in lower

concentrations of organic and inorganic pollutants (with the exception of iron, manganese and chlorides) in the recirculated leachate than in the leachate from the control fill. Although the recirculation of leachate through the simulated fills should concentrate some of the constituents in the leachate, the trends observed for the organic and inorganic parameters measured indicated that most constituents were reduced in concentration.

The biochemical and chemical oxygen demand (BOD_5 and COD) were initially low in the leachate from both fills due to the washing action of the initial water addition. However, by the second week the concentrations of both parameters were higher in the control leachate than in the recirculated leachate and continued to increase during the remainder of the test period. By the end of the test phase, the control leachate had COD and BOD_5 values of 15,600 and 9,300 mg/l respectively while the recirculated leachate had a COD of 4,270 mg/l and a BOD_5 of 3,500 mg/l. The total organic carbon (TOC) concentration in the recirculated leachate was initially somewhat higher than in the control, but it too was less than in the control leachate by the first week and remained lower throughout the test period. Although the variation shown by this parameter was not as great as that displayed by the BOD_5 and COD analyses, the final concentrations observed were 3,409 mg/l for the control and 1,067 mg/l for the recirculated leachate.

The concentrations of organic and ammonia nitrogen, nitrates and phosphates were also lower in the recirculated leachate than in the leachate from the control fill. As was the case with BOD_5 and COD, the initial concentrations of organic and ammonia nitrogen and nitrates were low due

to the washing action mentioned previously. However, the phosphate concentrations were at a maximum initially because the soluble phosphates were leached from the fills by the initial water addition (see Figure 9). The ammonia nitrogen concentration increased steadily in the control to a final value of 264 mg/l while the recirculated leachate displayed a slower change to 62 mg/l. The trends for organic nitrogen were initially similar for the two leachates, however the control showed a much slower increase in organic nitrogen than it did for ammonia. The final organic nitrogen concentrations observed in the control and recirculated leachate were 43 mg/l and nil respectively. The nitrate concentration in the recirculated leachate fluctuated considerably during the first 3 weeks (possibly because of the persistence of aerobic conditions towards the top of the fill) but was lower than the concentrations in the control leachate by the second week and decreased with the onset of more reduced conditions and possible greater biological utilization of nitrogen in the recirculated fill.

After the initial peak values, the phosphate concentrations in both leachates were very low. However, the level of phosphate in the recirculated leachate indicate some consumption of phosphate by the biological population in the fill. This hold-back of phosphate within the recirculating fill resulted in a final concentration of 0.26 mg/l, while the control leachate had a concentration of 1.5 mg/l.

The concentrations of calcium, magnesium, sodium, total solids and total hardness of the recirculated leachate were also lower than the concentrations found in the control at the end of the study phase. The concentrations of calcium, hardness and total solids in the control leachate increased rapidly and were always much higher than in the recircu-

lated leachate. The final observed concentrations for calcium, hardness and total solids in the control leachate were 545 mg/l, 2,449 mg/l and 4,840 mg/l while their corresponding concentrations in the recirculated leachate were 340 mg/l, 1,146 mg/l and 3,987 mg/l. The magnesium and sodium concentration in the two leachates did not show as much variation as calcium but their final concentrations in the recirculated leachate were less than in the control (45 mg/l of magnesium and 59 mg/l of sodium in the recirculated leachate, and 75 mg/l of magnesium and 148 mg/l of sodium in the control).

The chloride concentration of the control leachate was initially higher than the recirculated leachate but the final observed chloride concentration in the recirculated leachate was 270 mg/l or slightly lower than the 308 mg/l in the control.

The initial sulfate concentration of the recirculated leachate was lower than the concentration in the control leachate and the iron and manganese concentrations were higher. The final observed concentrations of sulfate, iron and manganese in the control were nil, 420 mg/l and 16 mg/l, while the concentrations found in the recirculated leachate were essentially nil for sulfate, 13 mg/l of iron and 50 mg/l of manganese.

Effect of Recirculation on Total Environmental Pollution

Based on the leachate production of the control fill presented in Table 9, the total mass of materials leached from the control fill during the test period was calculated. The total mass of materials present in the recirculated leachate at the end of the test period was also calculated using the volume present in the system at the end of the period plus the sample volume which had been removed. The mass of the various materials are tabulated in Table 11.

Table 11

Quantities of Materials Leached from the
Simulated Landfills During the 197-Day Study Period

Leachate Constituent	Quantity of Leached Material, lbs.	
	Recirculating Fill*	Control Fill*
COD	1.96	2.95
BOD_5	1.61	1.95
TOC	0.49	0.73
TSS	0.10	0.38
VSS	0.05	0.037
TS	1.84	1.84
Alkalinity as $CaCO_3$	0.62	0.49
Acidity as $CaCO_3$	0.15	0.44
Total Hardness as $CaCO_3$	0.53	0.41
Acetic Acid	0.28	0.61
Propionic Acid	0.33	0.27
Butyric Acid	0.13	0.13
Valeric Acid	0.13	0.36
Phosphate as $PO_4^{\equiv}$	0.00012	0.0071
Organic Nitrogen as N	0.0018	0.025
Ammonia Nitrogen as N	0.03	0.043
Chlorides as Cl^-	0.12	0.13
Calcium	0.16	0.12
Magnesium	0.021	0.018
Manganese	0.023	0.0023
Sodium	0.027	0.040
Iron	0.006	0.019

* Based on a total volume of 55 gallons and the concentrations at end of study period.
** See Table 8 for leachate volumes.

A comparison of the quantities leached from each fill by the end of the 197-day test period indicated that a larger quantity of each material was extracted and/or attenuated from the recirculating fill than from the control. In terms of a mass flow rate, this implied that pollutants were being removed and/or converted at a faster rate from the recirculating fill than from the control. This also indicated that the control fill would require a longer period of time to stabilize than the recirculating fill, but that initially the recirculating leachate would result in a greater pollutional load if it was discharged to the environment.

The preliminary results to date indicate that if leachate recirculation is practiced, leachate produced by a landfill must be collected and held until the fill has been stabilized. When stabilization is complete, the collected leachate could be discharged directly to the environment or treated and then discharged depending upon conditions. However, since it has already been demonstrated that recirculation serves to provide an eventual reduction in the concentration of extracted materials in the leachate, the quantities of organic pollutants released to the environment will ultimately be less than from a freely leaching landfill. Insufficient data have been collected to date to permit a definite statement about the quantity of inorganic pollutants released to the environment when stabilization has been completed, but it is probable that the total quantity of inorganic pollutants would remain unchanged and would accumulate in the leachate.

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Annual Progress Report

LANDFILL STABILIZATION WITH LEACHATE RECYCLE

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ABSTRACT

The information presented in the annual progress report has resulted from initial studies on the feasibility of a leachate recycle system which will provide leachate treatment and pollution control as well as accelerated rates of biological stabilization within sanitary landfills. The ultimate aims of the project are: (a) to study and demonstrate the feasibility of increasing landfill stabilization rates and provide concomitant leachate treatment by leachate capture and recycle through a simulated sanitary landfill; (b) to identify and develop control parameters and techniques including methods for determining rates of decomposition and stabilization in the landfill, rates of accumulation and/or disappearance of intermediates and end-products in the leachate, and the extent and type of internal or external control necessary to maintain an optimum environment within the fill; and (c) to provide recommended design, operational and control methods applicable to conventional sanitary landfill practice.

In the phases of the study reported herein, four simulated landfill containment vessels and support structures have been designed and constructed, the test refuse has been prepared and placed, operational procedures have been developed, and sampling and analysis of samples from both the control and recirculating landfills have been undertaken. The preliminary results have indicated that if leachate recirculation is practiced, leachate produced by a landfill must be collected and contained until the fill has completed its most rapid biological stabilization processes. When this has occurred, the collected leachate could be discharged directly into the environment or treated and then discharged depending upon prevailing conditions. Recirculation of leachate through the simu-

lated landfills has reduced the concentration of extracted materials in the leachate and thereby provided a new method of environmental control of potential utility to the management of solid waste disposal systems.

Additional studies are being conducted in accordance with the research plan originally proposed in order to substantiate existing trends and explore the possibility of providing operational control in the form of pH modification, seeding and/or nutrient additions. Stabilization rates and leachate characteristics will again be documented and will be supplemented with temperature control and gas monitoring.

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SECTION I

CONCLUSIONS

1. The collection and recirculation of leachate through a simulated sanitary landfill resulted in a more rapid development of an active anaerobic biological population and a resultant higher rate of landfill stabilization than was associated with a landfill constructed and operated without recirculation.
2. The eventual concentration of most organic and inorganic pollutants in the leachate from the recirculating landfill was lower than that found in the non-recirculating landfill and pollutants were leached and/or attenuated at a more rapid rate.
3. Recirculation of leachate increased the rate of surface settlement, provided an effective means of biological treatment of the leachate within the landfill, and enhanced the predictability of the landfill with respect to satisfying environmental quality standards, determining needs for additional leachate treatment and/or discharge regulation, and selecting ultimate site use alternatives.
4. The ultimate effect of leachate recirculation is the reduction and control of total pollution eventually discharged to the environment by a landfill and the improvement of the sanitary landfill method of solid waste disposal as a land reclamation method.
5. The present study should be continued to verify the trends observed during the initial project period and the additional recirculating fills should be used to evaluate the relative merits of seeding and/or pH and nutrient control.

SECTION II

RECOMMENDATIONS

The data to date have shown several basic trends which imply that leachate recirculation will increase the rate of landfill stabilization, reduce the concentration of organic and inorganic pollutants in the leachate, and permit ultimate discharge with or without additional treatment. Continuing research with the initial two simulated landfills is needed to verify the existing trends and to determine if inhibitory substances will accumulate with time in the recirculated leachate. The two additional simulated recirculating fills constructed to determine the effect of pH control and nutrient addition on the process and equipped with gas monitoring equipment and larger sampling ports should provide supporting information.

The two new recirculating fills should demonstrate the value of pH control and/or nutrient addition. The initial pH in the recirculated leachate was well below the optimum range for the methane forming bacteria indicating that stabilization went through the acid fermentation stage followed subsequently by methane fermentation. The small quantity of organic nitrogen present in the synthetic refuse may also have been a limiting factor in stabilization and the addition of a nitrogenous source could prove valuable. Control of pH may be achieved by placing layers of limestone at intervals in the fill material or adding lime or other neutralizing materials to the recirculating leachate. The addition of nutrients may be achieved by mixing digested sludge with the synthetic refuse or adding fertilizer to the recirculating leachate.

Gas monitoring equipment installed on both the new and existing simulated fills will provide measurements of the gaseous reaction products as they are generated. Larger sampling ports should also allow for the collection of larger and more representative solid waste samples to be removed from the fills and permit visual comparison of the refuse in the new and existing fills.

SECTION III

INTRODUCTION

The sanitary landfill method of solid waste disposal has been used to economically dispose of waste generated by both metropolitan and rural communities and also to reclaim unsuitable land for recreational and other uses. However, the potential for land reclamation has not yet been fully realized due primarily to the time required for the fill to stabilize (often twenty years or longer).

Documentation of several instances of ground and surface water pollution by leachate and surface runoff from sanitary landfills has resulted in construction and operation criteria often requiring the exclusion of surface runoff and ground water from landfills. Diversion of all moisture except direct precipitation from a landfill results in much less leachate production, but also reduces the rate of biological stabilization due to a lack of moisture and necessary nutrient transport. This retardation of biological activity in the fill results in an extension of the period required for stabilization, thereby limiting and/or delaying plans for land reclamation and ultimate use.

It was the purpose of this research to demonstrate that the collection of leachate and its recirculation through a simulated landfill would:

1. increase the utility of the sanitary landfill as a solid waste treatment and land reclamation process by increasing the rate and predictability of biological stabilization; and
2. reduce the quantity of organic and inorganic pollutants in the leachate by utilizing and controlling the biological activity within the fill.

SECTION IV

REVIEW OF THE LITERATURE

Whenever refuse is deposited on land, some of its organic and inorganic constituents are subject to leaching as water percolating through the refuse carries these materials into aquifers, surface streams or impoundments. Such leaching of pollutants may seriously impair water quality and endanger the health and welfare of the community.

The leachate formed by such action has been defined as the contaminated liquid which is discharged from a landfill to either surface or subsurface receptors[11]. For pollution of ground water to occur, three conditions are required: (1) the refuse must be located over, adjacent to, or in an aquifer; (2) supersaturation must exist in the fill due mainly to the movement of ground water into the fill and percolation of precipitation and surface water runoff; and, (3) leached fluids must be produced and this leachate must be capable of entering an aquifer[23].

Effect of Landfills on Water Quality

Based on the study of an existing landfill in an abandoned gravel pit, Anderson and Dornbush[1] reported that ground water in the immediate vicinity of the landfill and in direct contact with the fill exhibited an increase in ionic strength and that the impairment of water quality by excess ions decreased with distance from the fill area. Analyses on the samples obtained at various depths from 22 wells located around the landfill indicated that the concentration of chlorides and sodium and the specific conductance were the most appropriate chemical parameters

of those employed to measure to leachate pollution. It was also reported that the pond downstream from the fill area served to reduce the hardness and alkalinity during the summer months.

Hughes, et al.[15-18, 32] investigated the characteristics of four active landfills of varying ages in northeastern Illinois. Piezometers were installed at various points in the landfills and core samples were obtained at the piezometer locations. The results indicated that ground water mounds had formed under each fill and that leachate moved away from the fill area through springs in the superficial sand layer around the fills and vertically downward into the subgrade. Analyses of samples revealed that ground water quality increased with age of the fill material and with distance from the fill area. Ground water quality also varied greatly over short vertical and horizontal distances within the fill.

Coe[5] reported from studies at the University of Southern California that the ground water under the Riverside Landfill contained BOD, chloride, sodium, and sulfate increases of 26, 10, 9 and 8 times respectively over the concentrations found in the natural and uncontaminated ground water. In general, the ground water at all points sampled downstream of the fill showed significant increases in mineral constituents, hardness, and alkalinity; however, the effects were considerably less than those found in ground water under the fill.

Calvert[2] reported an increase in hardness, calcium, magnesium, total solids and carbon dioxide in a well 500 feet from a refuse storage pit at a garbage reduction plant. Carpenter and Setter[3] sampled water at the bottom of a refuse fill and obtained average BOD, alkalinity and chloride concentrations of 1,987 mg/l, 3,867 mg/l, and 3,506 mg/l respectively. Lang[19] reported the pollution of well water 2,000 feet away

from a fill.

Davison[7] studied the characteristics of refuse trips in England and concluded that such effluents could promote the growth of bacterial slimes or fungus in groundwater supplies and lead to taste and odor problems.

The pollution of the surface water supply of Kansas City, Mo. reported by Hopkins and Papalisky[14] was attributed to the reactivation of an industrial waste landfill with the subsequent leaching of organic compounds directly into the Missouri River one mile above the city's water intake. A review of German experiences [21] has indicated the detection of pollution in surface waters 2.5 miles downstream from a solid waste disposal area.

Quantities of Leachate Produced by Landfills

Remson, et.al.[26] have developed a moisture routing model based on the equation of continuity to predict the quantity of leachate which would be produced by a landfill for a given refuse, soil, and precipitation pattern. Sample calculations for a hypothetical landfill composed of eight feet of compacted refuse and two feet of soil cover were provided together with characteristics of a municipal refuse. Calculations were simplified by assuming: (1) a fully vegetated fill surface with plants whose roots draw water from all parts of the soil cover but not the underlying fill; (2) no moisture removed by diffusing gases; (3) infiltration of all rainfall; (4) a soil cover and refuse with uniform hydraulic characteristics in all directions; and, (5) a freely draining landfill and substrata. The examples assumed instantaneous placement of a refuse at various moisture contents and at various times of the year.

The average rainfall was superimposed and the amounts of leachate produced calculated.

A graphical phase relationship presented by Fungaroli[11] showed a definite lag between initial addition of water and the production of leachate as well as a correlation between water added and leachate produced. The relationships between field capacity and dry density of the refuse and the effect of cover soil type on infiltration into the fill indicated that denser refuse yielded higher field capacity and therefore a longer time to saturate the landfill and produce leachate. A light clay loam proved to be the best cover material because of the longer time required to bring a given thickness to field capacity and allow percolation into the fill. It was concluded that leachate production could be attributed to refuse composition and placement, channeling and/or type of wetting front.

Experiments by Merz and Stone[21] with landfill cells of approximately 20 feet in depth and covered with two feet of earth indicated that little leachate percolated into the subgrade beneath the landfills. Water was applied in sufficient quantities to the refuse cells by a sprinkler system so as to augment the natural rainfall and match the yearly rainfall of Seattle, Washington for one cell and to provide enough water to allow the growth of a thick turf on the other. The moisture content of the soil cover, refuse and subgrade was obtained from core samples taken at various points in the cells. Differences in moisture content at different levels (bands) in the cells was noted. Except for the soil cover, the top band of the cell simulating rainfall patterns of Seattle, was always drier than the other bands. During the final year of the project, the middle band maintained a higher moisture

content than the bottom band thereby indicating that the fill material had a high holding capacity. The adobe-shale subgrade beneath the cell maintained a moisture content only seven percent greater than native soils taken from the same depth. The earth cover of the other cell had a lower moisture content than the three bands at all times except for two core samples. There was no relationship between the moisture content of the top and middle bands and the subgrade averaged about the same water content as observed before for the other cell until it was accidently flooded. After flooding, the moisture content of the subgrade increased 38 percent.

Characteristics of Leachate Produced by Landfills

Theoretically any time that the amount of water entering a fill exceeds the field capacity of the deposited refuse, leachate will be produced and discharged. Leachate characteristics vary widely and there is no general way to forecast the exact composition of leachate which may be associated with a fill at any time. They are influenced not only by the material in the fill but also the chemical and physical characteristics of the percolating water and the soil adjacent to the fill or used for cover[27]. In almost all instances, leachate will be composed of concentrations of pollutants in the form of dissolved and finely suspended solids and microbial waste products[13].

Several studies have been performed to ascertain the characteristics of leachate. Coe[5] reported that the color of leachate ranged from green to brown, and that odors were similar to those of garbage (decomposing food stuffs) and oil and grease (hydrocarbons). Qasim[24] noted that the initial leachate samples were dark green and became darker and spetic soon after collection.

A study conducted in California demonstrated that continuous water movement through one acre foot of refuse would leach approximately 1.5

tons of sodium plus potassium, 1.0 ton of calcium plus magnesium, 0.91 ton of chloride, 0.23 ton of sulfate and 3.9 tons of bicarbonate within one year.[20]

Qasim and Burchinal [24,25] have reported experimental results obtained from examination of leachate produced from simulated landfills consisting of 36-inch concrete cylinders containing municipal refuse and covered to exclude precipitation. Water was applied by an internal sprinkling system and leachate samples were collected and analyzed for alkalinity, acidity, pH, BOD, total hardness, calcium, magnesium, sodium, potassium, iron, sulfate, phosphate, chlorides, nitrogen, solids, tanin and lignin, coliforms and total plate counts. Leachate analyses indicated an initial increase of pollutants which decreased after four weeks depending upon the depth of fill and extent of stabilization. The deeper fills took longer to become saturated so that leaching started later. Moreover, leachate liquors from the deeper fills were stronger although concentrations of pollutants per foot of fill decreased as the depth of fill increased.

Fungaroli and Steiner[12] have reported the results from examination of leachate from an insulated lysimeter. The leachate was generally acidic with the usual pH range between 5.0 and 6.5 except for some high and low peaks. Erratic pH occurred during low leachate production whereas relatively constant pH corresponded to periods of large production. This implied that the volumetric flow rate of leachate through the refuse was a moderating factor for pH. In addition, during low flow periods when the pH was greater than 5.5, the iron concentration in the leachate was low, about 100 mg/l. Conversely, when leachate production was high and the pH less than 5.5, the iron concentration was high. The maximum concentration for both ferric and ferrous iron exceeded 1600 mg/l. The

quantity of leachate produced also influenced the total solids concentration. The total solids increased with increasing leachate volume and decreased with decreasing volume. This indicated the "washing-action" as the leachate moved through the refuse. Similarly, after the initially high concentration of 50,000 mg/l COD, the COD remained between 20,000 to 22,000 mg/l during the duration of the two-year study. The leachate was also analyzed for chlorides, copper, zinc, nitrogen, phosphate, sodium, sulfate, and hardness; however, now trends or interrelationships between various ions were apparent.

Merz[27] reported results from examination of leachate from two "percolation bins" containing ten feet of compacted domestic refuse. The concentration of the organic and inorganic components was high in the first samples of leachate and increased for five weeks. The initial BOD was 33,100 mg/l and remained high for eight months. An 80 percent drop in BOD occurred after eight months and after 13 months the BOD had been reduced to 375 mg/l. The maximum ion concentration in the leachate was 10 to 20 times the concentration found in the water applied to the refuse. The ammonia, organic nitrogen and phosphate concentrations of the leachate were as much as 10,000 times the concentration found in natural waters. It was concluded that continuous leaching of an acre-foot of fill would result in minimum extraction of about 1.5 tons of sodium and potassium, 1.0 ton of calcium and magnesium, 0.91 ton of chlorides, 0.23 ton of sulfates, and 3.9 tons of bicarbonate. Removals of these quantities would take place in less than one year after which removals would continue slowly with some ions always remaining.

Table 1 contains the results of several leachate studies. These results are influenced by differences in refuse and percolating water and

Table 1
Variations of Leachate Composition

Analysis*	1	2	3	4	5	6	7	8	9		10	11	12	13	14		15	16	17
pH	5.6	5.9	8.3	-	-	-	-	-	7.63	5.60	7.4	6.4	4.9	5.6	8.4	5.7	6.3	6.48	5.88
Total Hardness (as $CaCO_3$)	8,120	3,260	537	-	8,700	500	900	290	8,120	650	-	-	2,500	30	-	-	7,600	13,100	10,950
Total Alkalinity (as $CaCO_3$)	8,100	1,710	1,290	-	-	-	-	-	9,520	730	-	-	-	-	9,450	100	10,630	16,200	20,850
Total Iron	305	336	219	1,000	-	-	40	2	305	6	-	206	152	28	-	-	175	546	860
Sodium	1,805	350	600	-	-	-	-	-	1,805	85	-	1,200	1,100	300	-	-	584	1,428	1,439
Potassium	1,860	655	-	-	-	-	-	-	1,860	28	-	-	920	110	-	-	1,050	2,535	3,770
Sulfate	630	1,220	99	-	940	24	225	100	730	248	248	940	970	65	-	-	615	1,002	768
Chloride	2,240	-	300	2,000	1,000	220	-	-	2,350	90	1,845	1,100	1,600	485	12,300	280	951	2,000	2,310
NO_3-N	-	5	18	-	-	-	-	-	-	-	-	-	196	10	-	-	-	-	-
NH_3-N	845	141	-	-	-	-	160	100	845	0.2	668	-	-	-	-	-	473	756	1,106
TON	550	152	-	-	-	-	-	-	550	2	101	-	-	-	-	-	288	664	1,416
COD	-	7,130	-	750,000	-	-	3,850	246	-	-	-	35,700	21,120	282	-	-	-	-	-
BOD	32,400	7,050	-	720,000	-	-	1,800	18	33,100	81	5,491	-	-	-	7,330	5.9	14,760	26,940	33,360
TDS	-	9,190	2,000	-	11,254	2,075	-	-	-	-	-	11,254	15,830	1,740	-	-	-	-	-
Specific Conductance	-	-	-	-	-	-	3,000	2,500	-	-	-	-	-	-	-		-	-	-

*All Analyses in mg/l except pH and specific conductance.

1., 2., 3. From reference 27 (No age of fill specified).
4. From reference 10. (Initial leachate).
5. From reference 10. (3 year old fill).
6. From reference 10. (15 year old fill).
7. From reference 9. (New fill).
8. From reference 9. (Old fill).
9. From reference 28. (Maximum and minimum).
10. From reference 22.
11. From reference 18.
12. From reference 11 (Site A).
13. From reference 11. (Site B).
14. From reference 3. (Maximum and minimum).
15. From reference 24, (Cylinder A, maximum).
16. From reference 24, (Cylinder B, max.)
17. From reference 24, (Cylinder C, maximum).

by limitations in sampling and analytical technique.

Parametric Considerations of Landfill Stabilization

One of the important parameters to be considered in a landfill is the moisture content of the material as placed. Refuse usually contains a large amount of paper which more than counteracts any moisture from the garbage fraction and other moist materials. However, moisture content increases with age and depth mainly because of infiltration and percolation of rainfall and surface water with time. In landfill studies by Eliassen[8], the moisture content ranged from 18.9 to 34.3 percent. Merz[27] found a moisture retention of 39.5 gallons per cubic yard of refuse from which cans and bottles had been removed. In the California studies[27], rainfall in that area did not penetrate a 7.5-feet thick fill.

The decomposition and stabilization in a landfill is dependent upon many factors including the moisture content. In general, the rate of chemical and biological reactions in a landfill increases with increasing moisture content. In the California study, where a large amount of water was applied to the fill, the settlement was about four times greater than a similar fill without water addition[27]. Other studies have also indicated that moderate amount of moisture in the landfill hastened decomposition[29]. Eliassen [8] carried out studies to determine the optimum moisture content for decomposition of landfill material. The procedure involved adding given amounts of moisture to 5-gram dried refuse samples. The results indicated that for fresh landfill material, the optimum moisture content for biological decomposition ranged between 50 and 70 percent and for older fills between 30 and 80 percent.

Another parameter of considerable significance is temperature.

Although a fill may be placed during cold weather, the material is insulated so that heat is not readily transmitted to the atmosphere. In Eliassen's study[8], the reactions in the fills were thermogenic and the temperatures at the depths of 3 and 7 feet were between 50-70°C; at a depth of 11 feet, the temperature ranged between 25-40°C even though the air temperature was between 10-20°C. These temperatures were in the range between the optimum temperatures for mesophilic (20-40°C) and thermophilic (50-70°C) organisms and both types of organisms may be presumed to assist in the decomposition of fill material.

Temperature has been monitored in several simulated landfill studies. Fungaroli[12] reported a peak temperature of 68°C within the first week of testing an insulated lysimeter, followed by a slow decline to 60°C and a subsequent rapid decrease to 30°C which remained constant during the remainder of the study. Sixteen days after placement, Carpenter and Setter[3] reported a temperature of 48°C at 3 feet and 55°C at 7 feet; the air temperature was about 24°C. Temperatures recorded after ten months indicated that the temperature of the fill had become stabilized at or near air temperature.

Merz and Stone[21] reported the maximum temperatures of two simulated fills to be 49°C and 42°C and that during the final two years of the study in one fill the temperature ranged from 16°C in the winter to 32°C in the summer; in the other fill, the temperature ranged from 12°C in the winter to 31°C in the summer.

Landfill Design and Operational Criteria

Some attempts have been made to include information on leachate characteristics and behavior in design considerations for sanitary landfills. Hughes[17] suggested several criteria including a thorough know-

ledge of the ground water flow system and soil characteristics at the proposed site. The hydrological and geological suitability of the site could then be ascertained with respect to retardation of ground water pollution. To preclude percolation and leaching, impermeable liners or covers were recommended together with the possible collection and disposal of leachate by an underdrain system. Culham and McHugh[6] have recommended the collection and treatment of leachate from landfills including consideration of filtration, flocculation, and the addition of lime for pH control. The diversion of water from landfill areas was emphasized as an important method for alleviating leachate problems which should be included in design and operational procedures. The pollutional characteristics of leachate can be attenuated or renovated as it moves through the underlying earth material before being discharged to the surface or into the ground water. Emrich[9] recommended one foot of suitable earth material for every foot of refuse. Anderson and Dornbush[33] reported that a pond and a trench located in the downstream direction from the slope of the water table improved the quality of water emanating from a refuse disposal area.

Site selection proposed by Cartwright and Sherman[4] included location of landfills in areas where soils of low permeability exist between the bottom of the fill and the highest estimated water table. An interim report[31] by the Department of Public Health, County of Los Angeles on the development of construction and use criteria for sanitary landfills recommended a geohydrological classification of landfill sites in addition to reduction of leachate problems by diversion of surface runoff in lined channels or storm drains, proper grading and use of relatively impervious surface materials, and construction of suitable barriers to restrict the

infiltration of ground water into the landfill. Hughes[33] discussed the importance of considering the stabilization time in selecting sites, particularly if treatment facilities are planned or if future use of the site is contemplated. Decrease in stabilization time was considered advantageous when leaching is rapid. Permeable cover material and rapid drainage will accelerate leaching and also increase the amount of leachate moving from the fill. The advantage of reducing infiltration into a landfill would be the reduction of quantity and rate of leachate produced. However, reduction of infiltration would extend the "polluting life" of the landfill and if the cover material used had a low permeability, it would tend to force the gases produced during decomposition laterally rather than upward through the surface and thereby cause problems due to the escape of gases at unsuspected locations.

SECTION V

MATERIALS AND METHODS

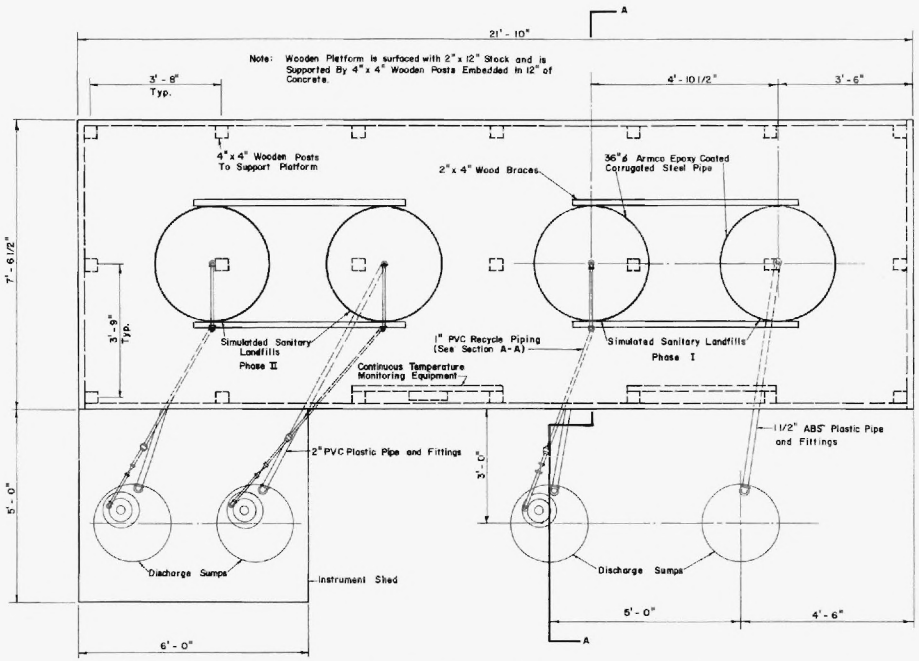
Simulated Landfill Construction

Since the purpose of the research was to develop and study the feasibility of a leachate recycle system to provide leachate treatment and pollution control as well as accelerated rates of biological stabilization within sanitary landfills, four simulated landfills were constructed on the campus of the Georgia Institute of Technology in Atlanta, Georgia. The construction was accomplished in two phases. The two fills of Phase I were completed in the spring of 1971; the two fills of Phase II were completed in the spring of 1972. All four simulated landfills were basically similar except for a few helpful modifications made during Phase II.

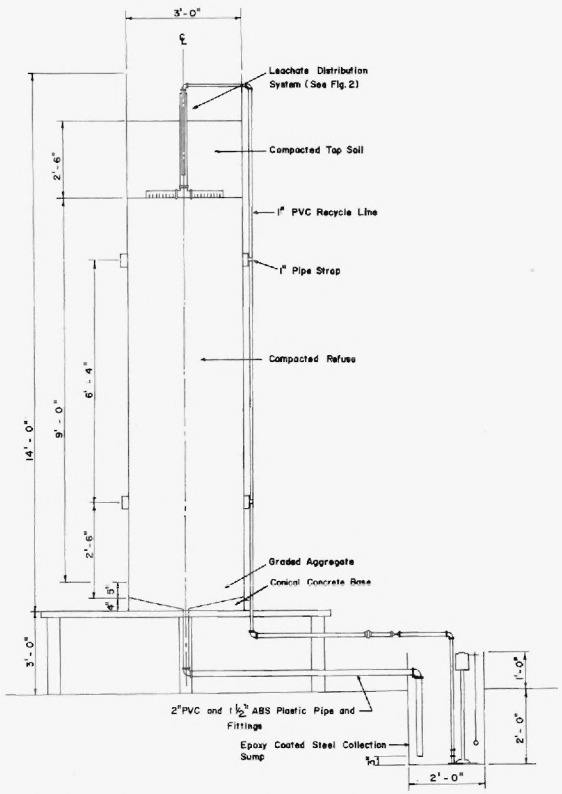
Phase I

The purpose of the initial phase was to demonstrate advantages of leachate recycle in accelerating the stabilization of sanitary landfills. Two simulated landfills were constructed; one fill had recirculation capabilities while the other fill was used as a control (no recycle).

The units were constructed 14-ft. deep by joining a 4-ft. section with a 10-ft. section of 36-in. ARMCO corrugated steel pipe. The pipes were lined with two coats of epoxy paint, placed on a wooden platform and secured with steel angles bolted around the base of each column. A conical concrete bottom with a 1.5-in. drain was formed in each simulated fill to seal the bottom of the pipe section and allow for the drainage of leachate. Nine inches of gravel (3/4-2 in.) were placed in the bottom of each column to prevent clogging by the compacted refuse. The two columns were connected



PLAN OF SIMULATED SANITARY LANDFILL APPARATUS
No Scale



SECTION A-A: RECIRCULATING SIMULATED LANDFILL
No Scale

Figure 1 Plan of Simulated Landfill Apparatus

by cross ties and guyed in two directions for stability. The configuration of the landfill structures is shown in Figure 1.

After the units had been erected, all joints and connections were caulked with a sealing compound to prevent air from entering the fill by any means other than some diffusion through the soil cover. Leachate from the simulated landfills was collected in epoxy-lined, 55-gallon drums. A 1.5-in. ABS plastic pipe provided for drainage of the leachate from the base of the simulated fills into the collection sumps. The drums were covered to exclude rainfall.

Initially it was proposed to have a proportional sampling device to automatically sample leachate from the sump of the control (non-recirculating fill). However, due to the small volume and the intermittant nature of the leachate from the control, the use of the device was not feasible. Instead, the drain line in the sump was kept plugged to prevent air from entering the fill through the drain and the drain was unplugged only to manually collect a leachate sample.

The leachate collected from the recirculating fill was removed from the sump and pumped back through a distributor buried between the top of the compacted refuse and the soil cover and allowed to percolate through the refuse (See Figure 1 and Figure 2). A float-operated sump pump was used for recirculation. The drain pipe in the sump was completely submerged in the leachate at all times by adjusting the float control to cut off about 6-in. above the drain discharge.

Three sampling ports were installed in each fill. The ports were constructed of 0.5-in. GVS pipe lengths inserted through the sides of the fill. The lengths were secured on both sides of the columns by nuts and rubber washers and the connections covered with sealing compound. Two of

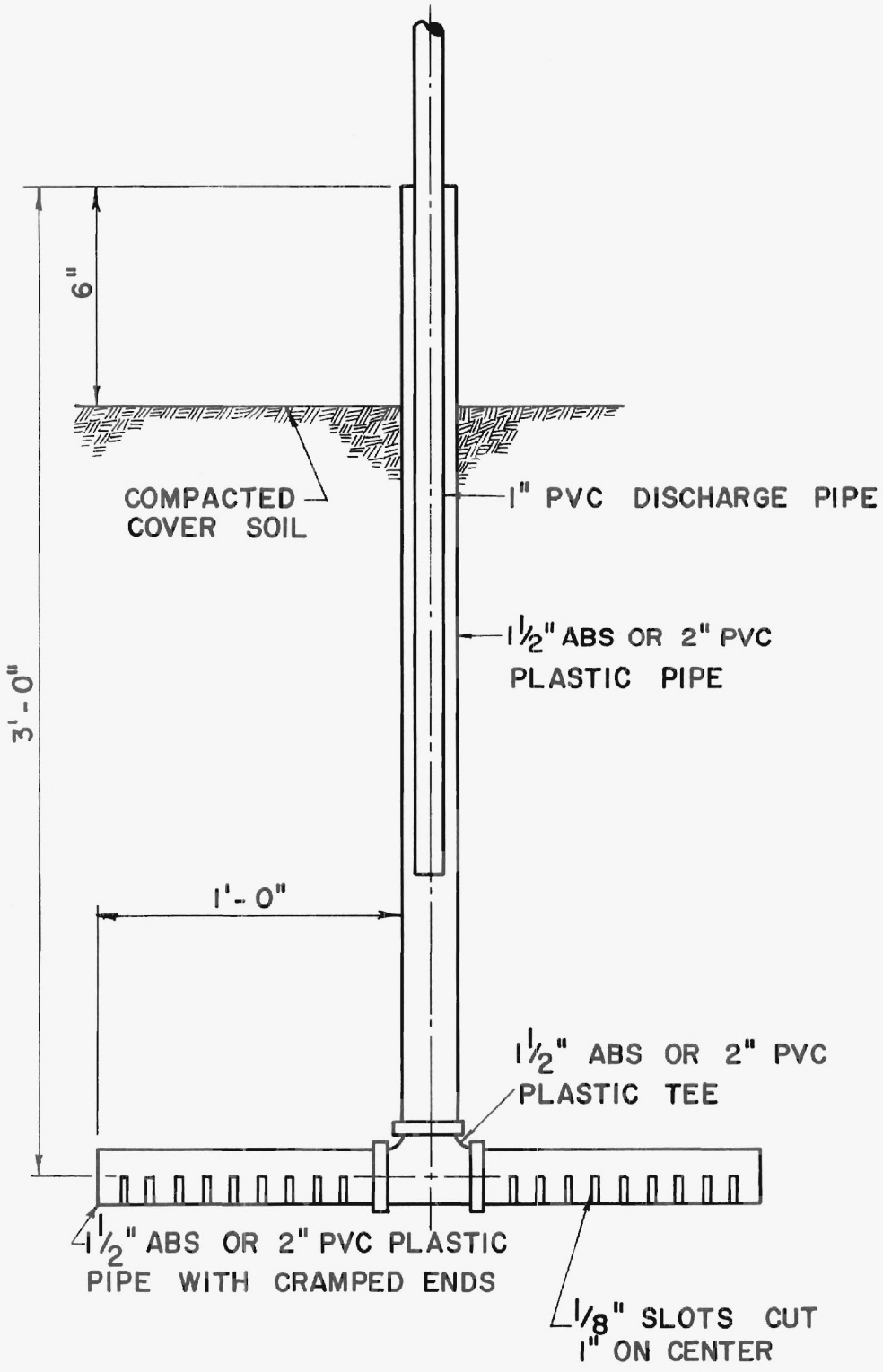


Figure 2 Leachate Distribution System

the ports were capped for future use as refuse sampling points and the third (center) port contained a temperature probe.

Ten feet of compacted simulated refuse was placed in each of the landfill columns. The composition indicated in Table 2 was chosen to reflect that of a typical municipal refuse. A total of 2,800 pounds of refuse was coursely ground with a brush chipper and the dry refuse was mixed in 200-lb. batches. The ground refuse with then hauled manually to the top of the simulated fills and dumped into the columns. The refuse was manually compacted in two 5-ft. lifts to a dry density of about 145 lbs./cu.yd.

Table 2

Composition of Simulated Refuse

Constituent	Dry Weight, Percent
Paper	50.0
Plastic	3.0
Glass	7.0
Garbage	25.0
Rags	5.0
Stone & Sand	5.0
Metal	4.0
Wood	1.0
	100.0

A two-week period elapsed before the placement of the soil cover, during which time the two fills, which were capped to exclude rainfall, settled approximately six inches. Due to this settlement, 30-in. of compacted top soil was placed over the refuse to bring the total height of each fill to 12 feet.

To expedite the production of leachate by the fills, 250 gallon of tap water were added after the placement of the compacted soil cover.

Based on the moisture holding capacity of synthetic refuses reported in other studies, the addition of 250 gallons of water was considered sufficient to bring the fills up to field capacity. However, since this quantity was applied in a 12-hr. period, some initial short-circuiting resulted. The addition of the water and the added weight of the cover soil also resulted in an initial settlement of 8.5 and 16.5 inches respectively in the controls and recirculating fills.

The production of 30 gallons of leachate by both fills after the initial water addition indicated that short-circuiting was occurring. To minimize short-circuiting by rainfall, a blanket of sod was placed over the soil cover to provide better distribution of rainfall across the fill surface and prevent water from flowing down the sides of the fills. Short-circuiting of recirculated leachate was minimized by using a gravity flow distributor and capping the ends of the distributor to direct the flow through the center of the fill.

Phase II

The purpose of the second phase was to illustrate the effects of recirculation plus nutrient addition and pH control on the stabilization of sanitary landfills. Therefore, two additional simulated landfills were constructed with recirculation capabilities. Because these units were completed approximately one year after construction of the initial two fills, it was possible to initiate some minor improvement.

The basic columns in Phase II were identical to those in Phase I (See Figure 1). However, the leachate drains in the conical concrete bases were changed from 1.5-in. ABS to 2.0-in. PVC pipe. The drains from each column discharged into 55-gallon drums which were equipped with polypropylene liners to provide a more corrosion resistant container.

The sumps for both fills were housed in a metal building (5' X 6') which provided cover and also served as an instrument shed.

Recirculation was provided as before except the distribution pipe (See Figure 2) was increased in diameter from 1.5-in. to 2.0-in. This provided more volume and thus reduced the chance of leachate overflowing the distributor system.

The refuse used in the Phase II units had the same composition (by weight) as that used in Phase I (See Table 2). The refuse was coarsely chopped manually and placed in the columns. The refuse was manually compacted in three 3.3-ft. lifts to a dry density of about 145 lbs./cu.yd. In one fill, 10 gallons of primary sewage sludge were added after each 3-ft. lift. To provide control, an equal volume of tap water was added to the other column.

To prevent clogging, the distributer was separated from the top of the refuse by a 3-in. layer of coarse gravel (1 to 3-in.). Two feet of soil cover were added immediately to each unit and rainfall was not excluded. In order to bring the fills up to field capacity, 220 gallons (30 gallons previously added by sludge and water) of tap water were added. To help alleviate short-circuiting, the water was added over a 72-hr. period. However, some short-circuiting did occur.

Due to possible differences in the manual compaction of the refuse, short-circuiting was slightly more prominent in the sludge containing fill than in the water containing fill. Sod was placed on top of the soil cover as in Phase I.

To facilitate the collection of representative refuse samples at periodic intervals, two sampling ports were installed on each of the new columns. The ports were constructed by placing a section of 3-in. ABS plastic pipe

through the sides of the columns. The pipes were equipped with threaded plugs and all joints and connections were caulked with sealing compound.

Sampling Procedures

Since sampling procedures have not been finalized for the second phase of the project, the following procedures pertain only to Phase I.

A 24-hr. sample was taken from the recirculating simulated landfill at one to three week intervals. An Instrumentation Specialities Company Model 780 Automatic Sample collector was used to collect 24, 560-ml. samples which were composited at the end of the sample period. A 1.0-liter aliquot was taken from the composite for analysis. Initially the remainder of the composite was discarded due to the large quantity of leachate collected from the recirculating fill, however, after 30 days of sampling, residual samples were returned to the collection sump.

Samples were obtained from the non-recirculating control fill whenever a sufficient quantity of leachate was produced from rainfall to yield a sample of from one to three liters. When a sufficient volume of leachate had collected in the base of the control fill, the drain line was unplugged and the leachate allowed to flow into a clean container. After all the leachate had been collected, the line was again plugged.

Analytical Methods

Analysis of Simulated Refuse

At the beginning of both Phase I and Phase II, a two-pound sample of the simulated refuse was collected and the organic fraction, consisting of paper, plastics, vegetable matter, meat, soap, and wood, was finely ground in a Wilen Mill. A portion of this sample was then ground in a

micromill and analyzed for carbon, hydrogen, and nitrogen with an F & M Model 185 CHN Analyzer. Another portion of the finely ground sample was digested in concentrated sulfuric acid, neutralized, diluted with distilled water and analyzed for Kjeldahl nitrogen with a Technicon Auto Analyzer; potassium, sodium, calcium, and magnesium with a Perkin-Elmer Atomic Absorption Spectrophotometer; and phosphates using the procedure outlined in Standard Methods.[30]

The refuse removed from the simulated landfills during the Phase I Study was analyzed for carbon, hydrogen, and nitrogen using the CHN analyzer, and moisture content and volatile solids using the procedures given in Standard Methods.

Analysis of Soil Characteristics

The characteristics of the cover soil used in the Phase I study were determined. The same type and quanity of soil was used in Phase II and additional soil analysis was therefore not considered necessary.

Two plexiglass columns were each filled with 2,000 grams of soil similar to that used as cover for the simulated landfills. The soil was leached with demineralized water to determine the potential contribution of various substances in the cover soil to the fill leachate. The leachate from one soil column was recirculated back through the column and the leachate from the second column was discharged to waste. This allowed for the determination of the total quantities of iron, calcium, magnesium, manganese, sodium, ammonia nitrogen, total nitrogen, and total organic carbon leached from the soil and also indicated to some extent the ion exchange capacity of the soil. The soil leachate was analyzed for sodium, calcium, magnesium, manganese, and iron with an atomic absorption Spectrophotometer; total organic carbon with a Beckman Total Carbon Analyzer;

and nitrogen with a Technicon Auto-Analyzer.

Analysis of Leachate Samples

The fill leachate samples (Phase I and Phase II) were analyzed for 5-day biochemical oxygen demand (BOD_5); total organic carbon (TOC), chemical oxygen demand (COD), total suspended solids (TSS), volatile suspended solids (VSS), total solids (TS), alkalinity, acidity, total hardness, total and ammonia nitrogen, phosphate, calcium magnesium, manganese, sodium, iron, chlorides, pH, and volatile acids. During the first 125 days of leachate production in the Phase I study, nitrate determinations were also made. Both specific ion electrodes and colormetric methods were tried, however, due to matrix interference difficulties, the results were unreliable. High concentrations of iron and chloride accounted for the problem. Since the nitrate concentration was relatively unimportant in determining the effects of the anaerobic system, subsequent analysis were not made. Sulfate was also determined during this period but it too was deleted when concentrations dropped to very low values.

Since it was the purpose of this research to determine the effect of leachate recirculation on landfill stabilization, the preceding analyses were considered adequate to reflect the process of stabilization in the fill and also demonstrate the possible accumulation of any pollutional substances.

Calcium, magnesium, manganese, sodium, and iron were measured with an atomic absorption spectrophotometer. Phosphates were determined by Hach Kit Methods and total and ammonium nitrogen were determined with an auto-analyzer. Chlorides were measured with an Orion Specific Ion Electrode using the method of known increment. Because the concentrations of the

hardness producing cations were determined, total hardness was found by the calculation method given in Standard Methods. Volatile acids were measured on the F & M Scientific 700 Chromatograph. The remaining analyses were performed according to Standard Methods .

SECTION VI

PRESENTATION OF THE DATA

Results of the analyses performed on the simulated refuse, cover soil, and leachate samples are presented in this section. However, since little information has been accumulated to date on the performance of the two simulated landfills in the second phase of the project, only data obtained in the Phase I study are presented. The time scales used in this presentation (time since placement of refuse and time since leachate production began) are related in that operating procedures allowed for the production of leachate 40 days after the placement of the simulated refuse.

Refuse Composition

Analysis of the organic portion of the refuse indicated an initial composition as shown in Table 3. The primary constituents of the refuse were carbon, hydrogen and oxygen with nitrogen, potassium, sodium and phosphate occurring in trace amounts.

Table 3

Initial Chemical Composition of the Organic Fraction of the Simulated Refuse

Refuse Constituent	Weight Percent
Carbon	47.20
Hydrogen	5.15
Oxygen	46.73
Nitrogen	0.65
Potassium	0.12
Sodium	0.12
Phosphate	0.03
	100.00
Volatile Solids	98.62

Table 4

Comparison of the Initial Composition of the Organic Fraction of the Refuse with the Composition of Samples Taken from the Simulated Fills at the End of Study Period

Refuse Constituent	Weight Percent		
	Initial	Control Landfill	Recirculating Landfill
Carbon	47.20	46.00	37.00
Hydrogen	5.15	5.97	4.68
Oxygen	46.73	47.80	57.98
Moisture	-	62.10	79.82
Volatile Solids	98.62	90.80	73.00

The comparison of the initial composition of the organic fraction of the refuse (paper, plastics, vegetable matter, meat, rags, and wood) with the composition of samples taken from the two simulated fills at the end of the study period (see Table 4) indicated that the refuse in both fills had undergone reductions in organic carbon and volatile solids. The reductions, however, were much more dramatic in the recirculation landfill.

Cover Soil Characteristics

Figure 3 and Table 5 indicate the results of the leaching column tests with the cover soil. Calcium, magnesium, and sodium were the only materials leached from the cover soil in measurable quantities. As was expected, the concentrations of iron in the leachate was very low and somewhat erratic. The concentrations of calcium, magnesium and sodium were initially high but dropped sharply during the first 30 hours of leaching.

Graphical intergration of the mass flow curves of each element indicated that the quantity of cover soil on each fill would produce only a negligible amount of each of the elements. Accordingly, the 2.5 feet of cover soil placed on the top of each fill should leach 58.9 grams of calcium, 11.9 grams of magnesium, and 1.27 grams of sodium in 144 hours of continuous leaching.

The equilibrium concentrations reached during the recirculation study indicated that the cover soil was a rather poor ion exchange medium for the indicated constituents. The highest affinity demonstrated by the soil was for calcium with sodium being held less than calcium but more than magnesium.

Table 5

Results of Cover Soil Leaching Experiments

Time, hr.	Mass Flow Rate, mg/hr				Time, hr.	Concentration, mg/l			
	Ca	Mg	Na	Fe		Ca	Mg	Na	Fe
0	3.86	0.59	0.80	0	0	1.1	0.1	0.5	0.2
4	3.19	0.50	0.76	0.04	24	1.6	0.2	0.5	0.3
7.5	1.68	0.21	0.29	0.04	48	3.3	0.5	0.6	0.2
32.5	0.63	0.04	0.17	0	72	3.4	0.5	1.0	0
52.5	0.50	0.04	0.08	0					
72	0.50	0.04	0.17	0.04					
144	0.25	0.04	0.04	-					
Total Mass Leached $\frac{gm}{gm} \times (10^6)$	48.9	4.95	1.06	-	Equilibrium Value mg/l	3.4	0.5	1.0	-

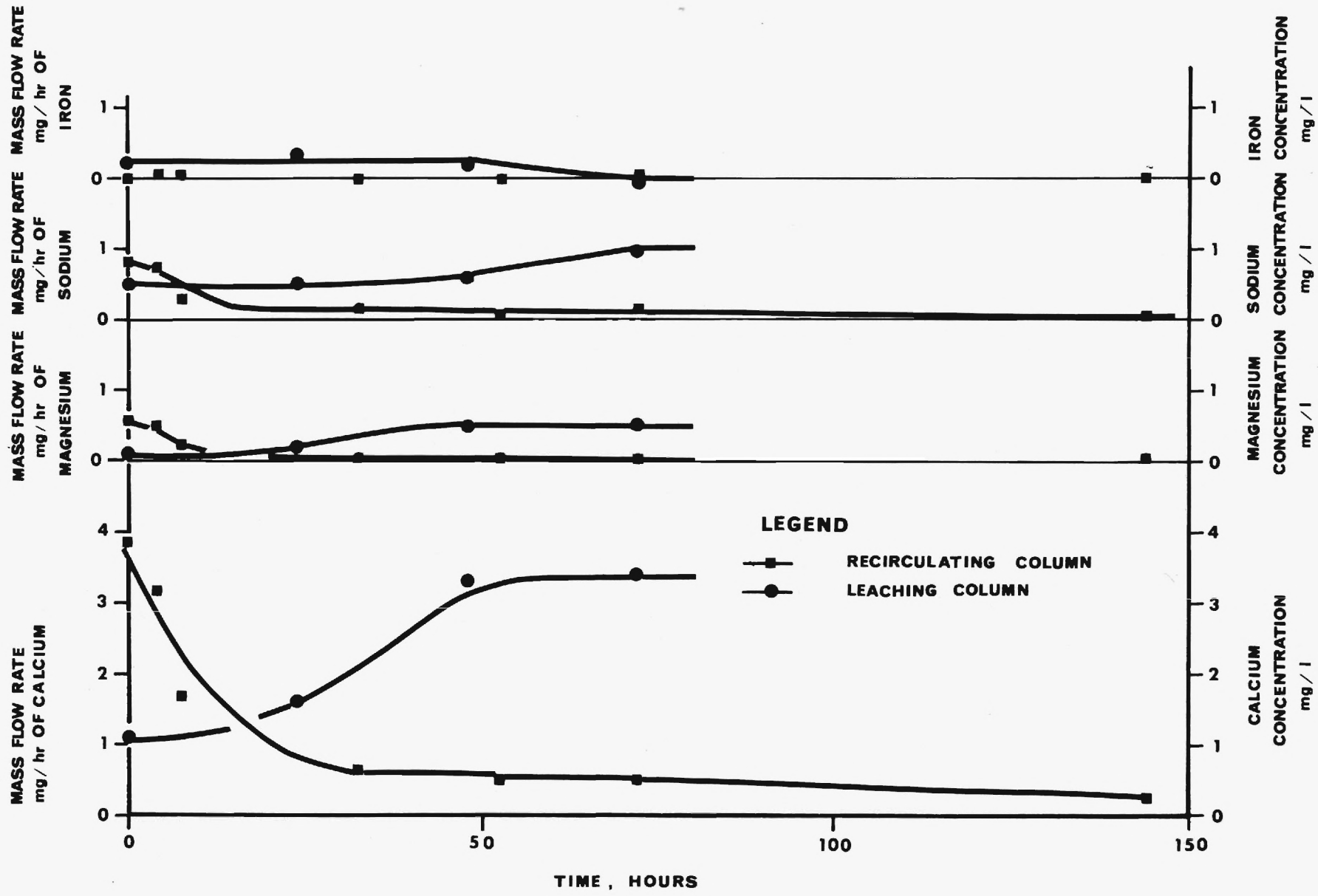


FIGURE 3 : RESULTS OF COVER SOIL LEACHING STUDY

Landfill Temperature

Temperature in the Phase I simulated landfill varied with daily ambient temperature fluctuations. The maximum (July) temperatures reached were 32°C in the control fill and 31°C in the recirculating fill; the minimum (December) termperatures were 5°C and 4°C respectively. The temperature variations in the control fill were slightly more dramatic than in the recirculating fill where temperature was moderated by the recycled leachate.

To determine whether insulation would provide control of large temperature fluctuations during extreme temperature periods, 3-in. fiberglas insulation was wrapped around the recirculating fill. The insulation was covered in 4 mil. polyethylene plastic to exclude moisture. The insulation was installed after 238 days and the temperature fluctuations were greatly reduced (See Figure 4). Insulation will be provided for the Phase II simulated fills.

Landfill Settlement

The cumulative surface settlement of both Phase I fills is shown in Table 6. As previously mentioned, both fills experienced settlement due to the placement of cover soil and the initial addition of water to the fills. This initial settlement was not included in the settlement data, and the cumulative settlement was calculated from the fill heights after the addition of cover soil and water.

Leachate Analysis

Cumulative precipitation intercepted by both Phase I fills is shown in Table 7. The total precipitation intercepted by each of the fills was

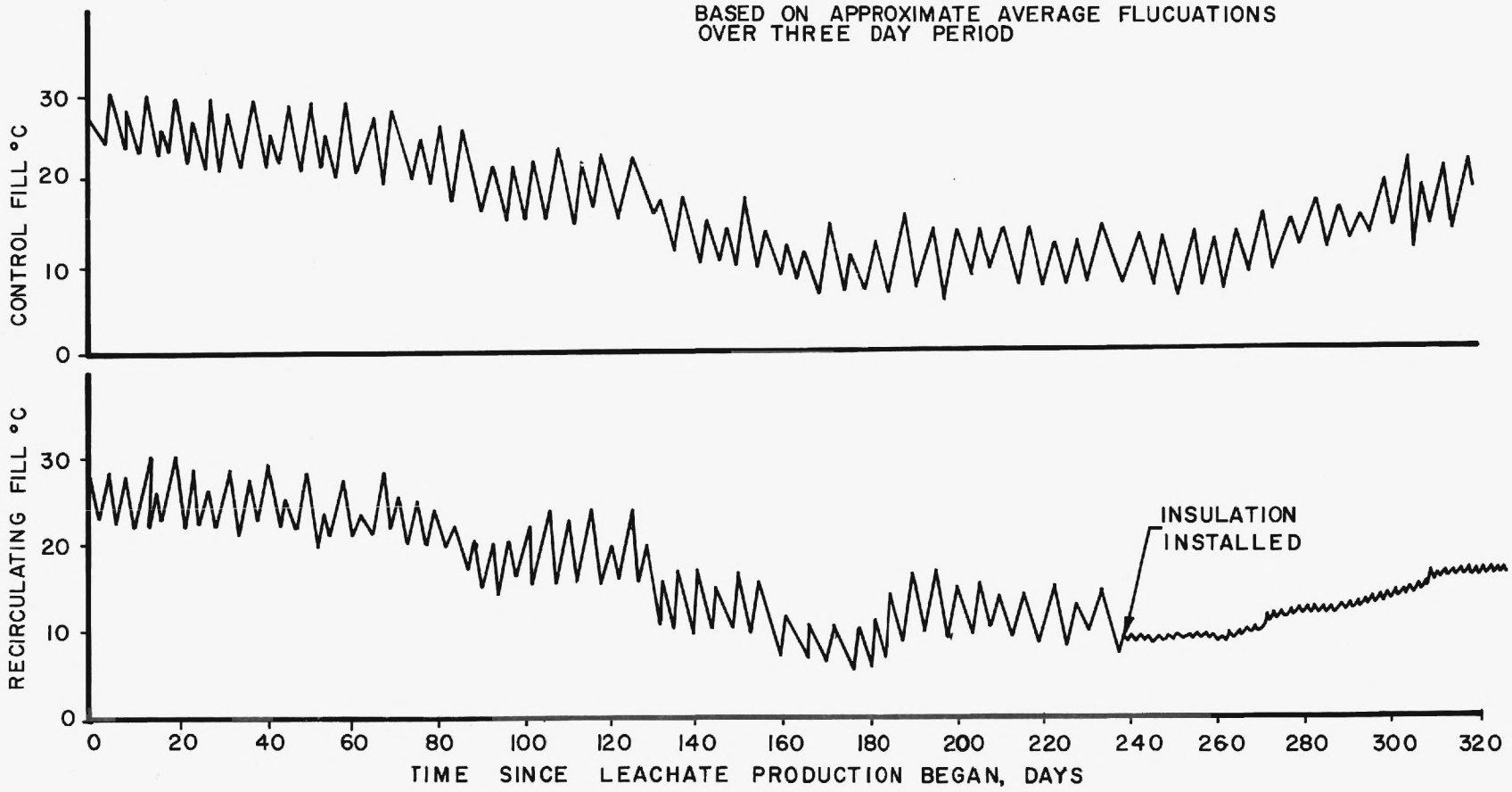


FIGURE 4: INTERNAL TEMPERATURE FLUCUATIONS OF THE SIMULATED LANDFILL

Table 6

Cumulative Surface Settlement
of the Simulated Landfills

Time Since Placement of Refuse days	Cumulative Surface Settlement, ft.	
	Recirculating Landfill	Control Landfill
40	0	0
42	1.0	.504
46	1.21	.790
50	1.21	.790
53	1.21	.790
57	1.22	.780
60	1.28	.780
64	-	.880
67	1.44	.880
71	1.48	.950
78	1.48	.950
90	1.48	.980
122	1.50	.990
134	1.50	1.010
157	1.50	1.019
180	1.50	1.027
200	1.50	1.032
220	1.51	1.042
250	1.51	1.053
300	1.51	1.059
320	1.51	1.070

Table 7

Daily and Cumulative Precipitation
Received by Both Landfills Since Refuse was Placed

Time Since Placement of Refuse days	Precipitation, in.	Cumulative Precipitation, in.
0	0	0
5*	0.37	0.37
21	0.68	1.05
27	0.23	1.28
29	1.22	2.50
32	0.37	2.87
33**	56.60	59.47
36	0.98	60.45
38	0.18	60.64
40	3.07	63.71
45	1.11	64.82
46	0.98	65.80
47	1.72	67.52
61	1.02	74.54
66	3.70	78.24
70	1.23	79.47
77	1.90	81.37
90	3.50	84.87
124	0.74	85.61
134	0.86	86.47
136	1.84	88.31
165	1.85	90.16
169	4.06	94.22
180	1.23	95.45
194	1.84	97.29
197	3.69	101.98
204	6.15	108.13
205	3.69	111.82
207	2.09	113.91
224	3.12	117.03
227	1.61	118.64
231	1.24	119.88
237	1.12	121.00
241	0.36	121.36
255	0.72	122.08
267	2.81	124.89
270	1.12	126.01
288	1.82	127.83
307	2.54	130.37

*Fills were capped until 5 days after refuse was placed.
**250 gals. of water were added to each fill to bring them to field capacity.
Note: Rainfall was measured daily.

Table 8

Cumulative Leachate Production
By the Control Landfill*

Time Since Placement of Refuse, days	Leachate Production, in.	Cumulative Leachate Production, in.
0	0	0
33	6.804	6.804
47	2.040	8.844
57	0.034	8.878
65	0.454	9.332
72	0.566	9.898
81	0.198	10.096
116	0.294	10.390
125	0.180	10.570
153	0.239	10.809
173	0.216	11.025
189	0.210	11.235
197	0.181	11.416
228	0.121	11.537
249	0.204	11.741
284	0.192	11.933
312	0.378	12.311

*Total leachate production by the control fill was 54.10 gals. including the 30 gals. initially obtained by addition of water to reach field capacity. Leachate was measured either when enough had accumulated in the control fill to provide a proportional sample of 1.5 liters or two days after rainfall.

130.37 inches including the water equivalent to 56.6 inches which was initially added to saturate the fills. Total leachate production from the control fill (see Table 8) was 12.311 inches (54.10 gals.) including the equivalent 6.804 inches (30 gals.) which were produced when the fills were initially saturated.

The initial leachate samples taken from the two fills were dark green in color and had a rotten garbage odor. The samples from the re-circulating fill later lost this characteristic color and odor, whereas the control fill samples became light green in color and acquired a putrid odor similar to that of the short-chained organic acids. Upon exposure to air, however, the color of these control samples rapidly changed from green to dark brown as the ferrous iron was oxidized.

The concentrations of extracted materials in the leachate obtained from the simulated landfills are tabulated in Tables 9 and 10 and displayed graphically in Figures 5 through 15.

Table 9

Concentrations of Extracted Materials in Leachates Obtained from Control Landfill

Time Since Leachate Production Began, days	0	14	24	32	39	48	81	116	125	153	173	189	197	228	249	284	312
COD, mg/l	4,320	9,150	10,380	10,260	12,000	11,700	9,200	10,100	11,700	12,200	12,300	14,400	15,600	18,100	15,600	13,300	13,800
BOD_5, mg/l	2,500	5,000	9,200	6,330	11,000	8,200	8,800	9,600	8,700	11,100	9,200	12,000	9,300	13,400	12,600	9,560	8,800
TOC, mg/l	1,230	1,910	2,622	2,622	2,802	2,835	2,864	2,259	2,418	2,680	2,696	3,049	3,409	5,000	3,590	3,000	2,930
TSS, mg/l	125	34	59	61	47	213	270	640	550	292	470	360	175	85	175	605	610
VSS, mg/l	45	20	47	52	37.6	93	160	332	314	182	268	210	104	76	141	283	286
TS, mg/l	2,442	5,819	6,323	8,300	8,736	6,789	5,530	7,250	7,358	7,620	7,875	8,320	8,130	12,500	8,780	7,716	7,167
Total Alkalinity, mg/l as $CaCO_3$	558	1,610	1,640	1,920	2,280	2,110	2,420	2,650	2,120	2,350	2,100	2,482	1,760	2,480	1,580	2,430	1,930
Total Acidity, mg/l as $CaCO_3$	690	1,100	1,350	1,400	1,780	2,170	1,836	1,390	2,090	2,230	2,780	2,865	3,260	3,460	2,610	2,000	2,400
pH	5.2	5.6	5.3	5.3	5.3	5.3	5.7	5.3	5.2	5.3	5.1	5.2	5.1	5.1	5.2	5.2	5.3
Total Hardness, mg/l as $CaCO_3$	450	1,400	1,850	1,810	1,940	1,754	1,410	1,429	1,694	2,232	2,354	2,306	2,449	5,555	3,463	2,424	2,299
Acetic Acid, mg/l	500	2,111	2,360	2,664	3,666	3,268	2,789	3,285	2,590	3,280	3,440	3,393	3,550	5,160	3,754	3,460	2,830
Propionic Acid, mg/l	369	1,595	1,834	2,038	2,313	2,108	1,875	2,625	2,110	2,290	2,190	2,400	2,214	2,840	1,742	1,640	1,580
Butyric Acid, mg/l	110	965	1,075	1,050	1,280	1,164	1,000	1,203	1,424	1,195	1,215	1,350	1,750	1,830	1,770	1,800	1,740
Valeric Acid, mg/l	Nil	425	575	625	535	612	643	893	656	708	652	730	801	1,000	705	750	768
Phosphate, mg/l $PO_4^{\equiv}$	26	3.0	5.0	7.8	2.8	2.9	3.3	4.2	3.4	2.8	1.7	1.6	1.5	1.3	1.5	0.9	1.1
Organic Nitrogen, mg/l as N	56	47	61.4	62	75	48	40	177	64	6	20	12	43	107	116	76	63
Ammonia Nitrogen, mg/l as N	56	150	167.6	187	185	192	148	103	130	260	214	218	264	117	52	110	103
Nitrate Nitrogen, mg/l NO_3^-	13.3	32	89	84	115	15.0	---	9.5	12	---	---	---	---	---	---	---	---
Chloride, mg/l	322	385	109.8	105.1	97.9	340	---	170	240	210	208	312	308	180	300	280	295
Sulfate, mg/l $SO_4^{=}$	84	126	108	81	156	17	2	7	1	16	---	---	---	---	---	---	---
Calcium, mg/l Ca	125	430	470	590	750	545	430	375	420	600	578	565	545	1,250	850	550	490
Magnesium, mg/l Mg	26	71.8	67	75	68	64	52	49	53	80	85	85	75	260	210	90	65
Manganese, mg/l Mn	3	10	5	6.2	8.8	8.5	10	7.5	10	16	14	15	16	18	19	12	12
Sodium, mg/l Na	63.8	125	132	132	143	150	180	118	135	155	154	155	148	160	140	85	140
Iron, mg/l Fe	9	21	70	30	95	65	60	155	230	200	300	290	420	185	250	370	440

Table 10

Concentrations of Extracted Materials in Leachates Obtained from Recirculating Landfill

Time Since Leachate Production Began, days	0	10	18	24	31	39	48	58	67	96	111	126	140	161	189	197	219	228	249	284	284	312
COD, mg/l	4,280	9,288	8,870	9,080	8,111	7,709	8,140	9,580	10,400	10,025	10,500	10,500	10,350	8,890	5,810	4,270	3,550	2,970	2,840	2,580	1,950	1,280
BOD_5, mg/l	2,750	5,200	6,900	6,800	4,300	5,400	6,202	6,400	6,380	7,200	8,700	8,500	10,100	9,405	6,650	3,500	2,860	1,400	2,500	2,420	760	760
TOC, mg/l	2,130	1,120	2,260	2,040	2,394	1,818	2,665	2,000	2,675	2,798	1,990	1,979	1,952	1,542	1,280	1,067	914	710	565	500	308	256
TSS, mg/l	93	13.6	12	36.5	70.5	25	37.0	120	301	143	222	258	385	187	232	220	131	122	145	124	67	305
VSS, mg/l	22.5	---	9	27.5	45	18.8	16.9	70	161	78	158	142	188	118	156	116	76	74	87	56	37	18
TS, mg/l	2,349	4,329	4,552	5,023	5,400	4,728	4,941	5,250	5,440	5,980	5,830	6,918	6,106	5,336	4,090	3,987	3,240	2,792	2,370	2,510	1,848	1,627
Total Alkalinity, mg/l as $CaCO_3$	302	700	865	1,080	1,200	1,370	1,525	1,438	1,035	1,900	2,350	1,640	1,670	1,640	1,550	1,342	1,115	952	980	925	738	692
Total Acidity, mg/l as $CaCO_3$	554	1,900	1,540	1,350	1,000	1,390	1,265	1,530	1,765	1,798	1,730	1,830	1,700	1,630	500	333	240	180	166	133	84	80
pH	5.05	4.8	5.0	5.1	5.3	5.4	5.3	5.3	5.1	5.4	5.5	5.3	5.3	5.2	6.3	6.6	6.8	6.9	7.0	7.1	7.4	7.3
Total Hardness, mg/l as $CaCO_3$	370	895	880	1,010	890	1,040	1,222	1,483	1,532	1,701	1,987	1,495	2,296	1,948	1,469	1,146	978	677	539	661	513	377
Acetic Acid, mg/l	1,638	556	2,000	1,843	1,475	1,583	1,795	2,146	2,438	2,742	2,438	2,470	2,380	1,877	2,925	608	734	770	670	111	234	365
Propionic Acid, mg/l	960	394	1,242	1,467	1,554	1,594	1,580	1,752	1,953	2,203	1,953	1,865	2,020	1,472	1,995	714	195	111	104	57	223	110
Butyric Acid, mg/l	1,300	235	1,235	1,163	1,375	1,250	1,200	1,198	1,094	1,156	1,047	1,124	937	735	665	286	194	68	65	Nil	62	44
Valeric Acid, mg/l	500	735	50	833	688	670	714	800	858	857	786	842	625	556	585	276	87	65	50	Nil	35	Nil
Phosphate, mg/l $PO_4^{\equiv}$	22	1.5	2.1	0.65	0.81	0.67	0.82	0.85	0.98	0.65	0.38	0.50	0.39	0.82	0.47	0.26	0.24	0.07	0.08	0.09	0.12	0.09
Organic Nitrogen, mg/l as N	20	0	30	405	37.5	39.5	41	30	39	62	92	28	7	3	4	Nil	Nil	1	3	2	1	7
Ammonia Nitrogen, mg/l as N	70	68	113.5	86.5	77.5	76.5	64	69	81	84	80	71	135	126	80	62	56	39	31	35	27	13
Nitrate Nitrogen, mg/l NO_3^-	6.2	71.4	56.6	76.6	48	49	11.0	11.5	12.0	16.0	21.0	14.0	---	---	---	---	---	---	---	---	---	---
Chloride, mg/l	210	210	248	94.5	91	115	220	164	176	140	188	170	210	236	300	270	260	248	224	220	218	202
Sulfate, mg/l $SO_4^{\equiv}$	102	138	81	51	30	12	11	Nil	12	2	1	3	---	---	---	---	---	---	---	---	---	---
Calcium, mg/l Ca	60	315	350	435	420	430	420	415	440	500	550	385	600	475	400	340	290	190	145	175	135	82
Magnesium, mg/l Mg	16.5	59	53.5	62.5	56	56	50	50	53	55	62	44	70	60	50	45	40	40	38	40	35	38
Manganese, mg/l Mn	4	30	50	65	62	62	75	75	80	80	85	60	93	80	59	50	44	19	10	19	14	8
Sodium, mg/l Na	61.5	109	81.4	91.4	85	84	95	85	88	90	98	70	84	75	61	59	50	60	55	60	55	75
Iron, mg/l Fe	4.4	19.5	19	80	43	110	25	35	40	45	110	150	150	210	90	13	5	1.4	1.9	14	4	1.2

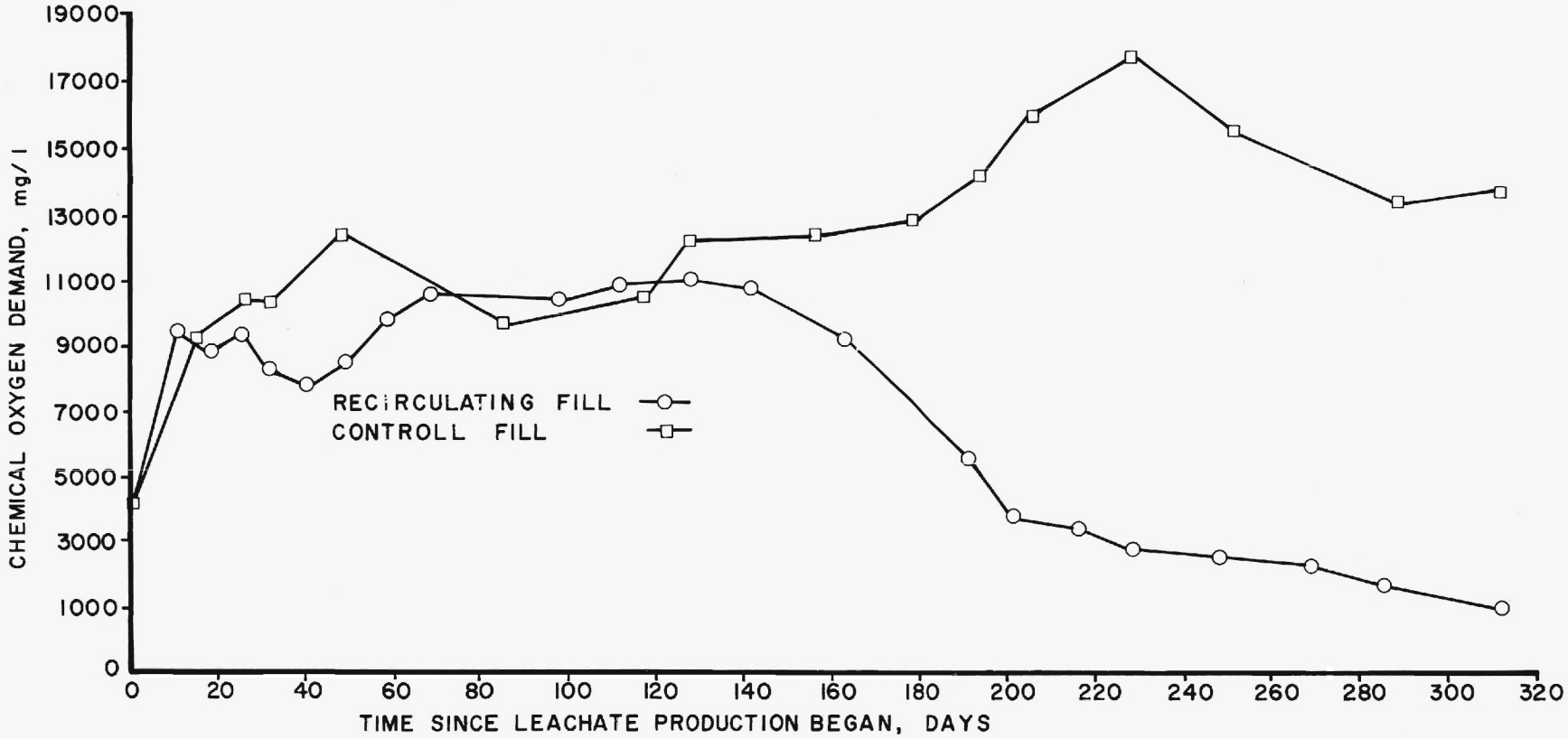


FIGURE 5: CHEMICAL OXYGEN DEMAND OF LEACHATE

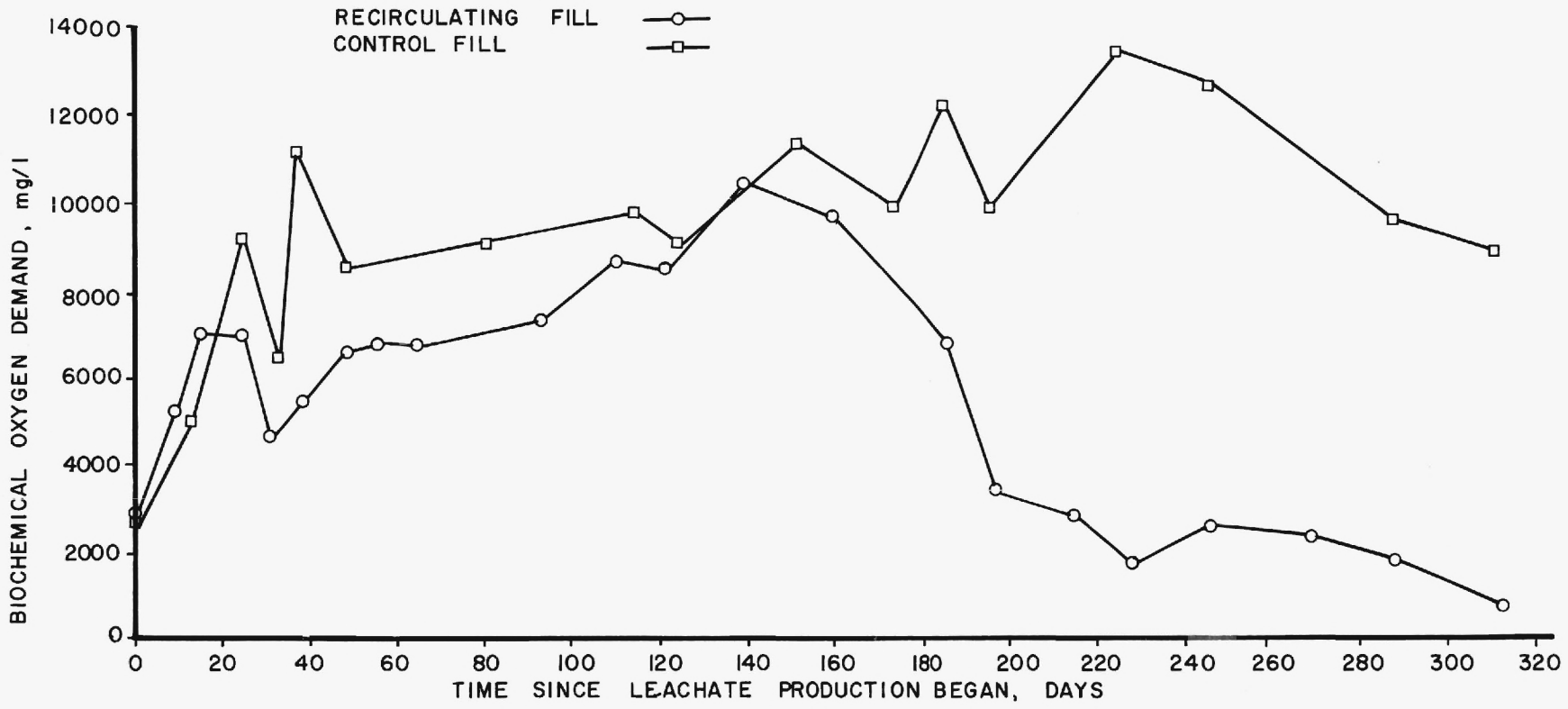


FIGURE 6: BIOCHEMICAL OXYGEN DEMAND OF LEACHATE

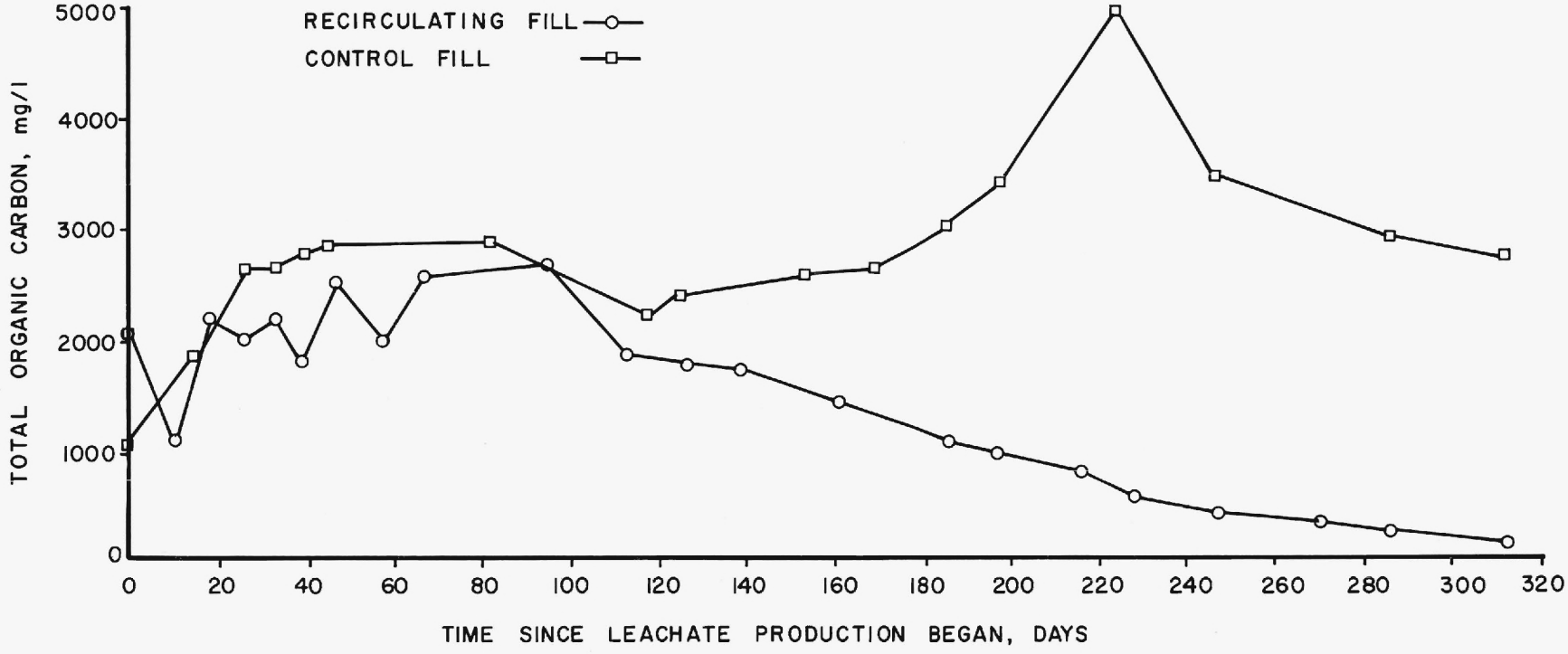


FIGURE 7: TOTAL ORGANIC CARBON CONCENTRATION OF LEACHATE

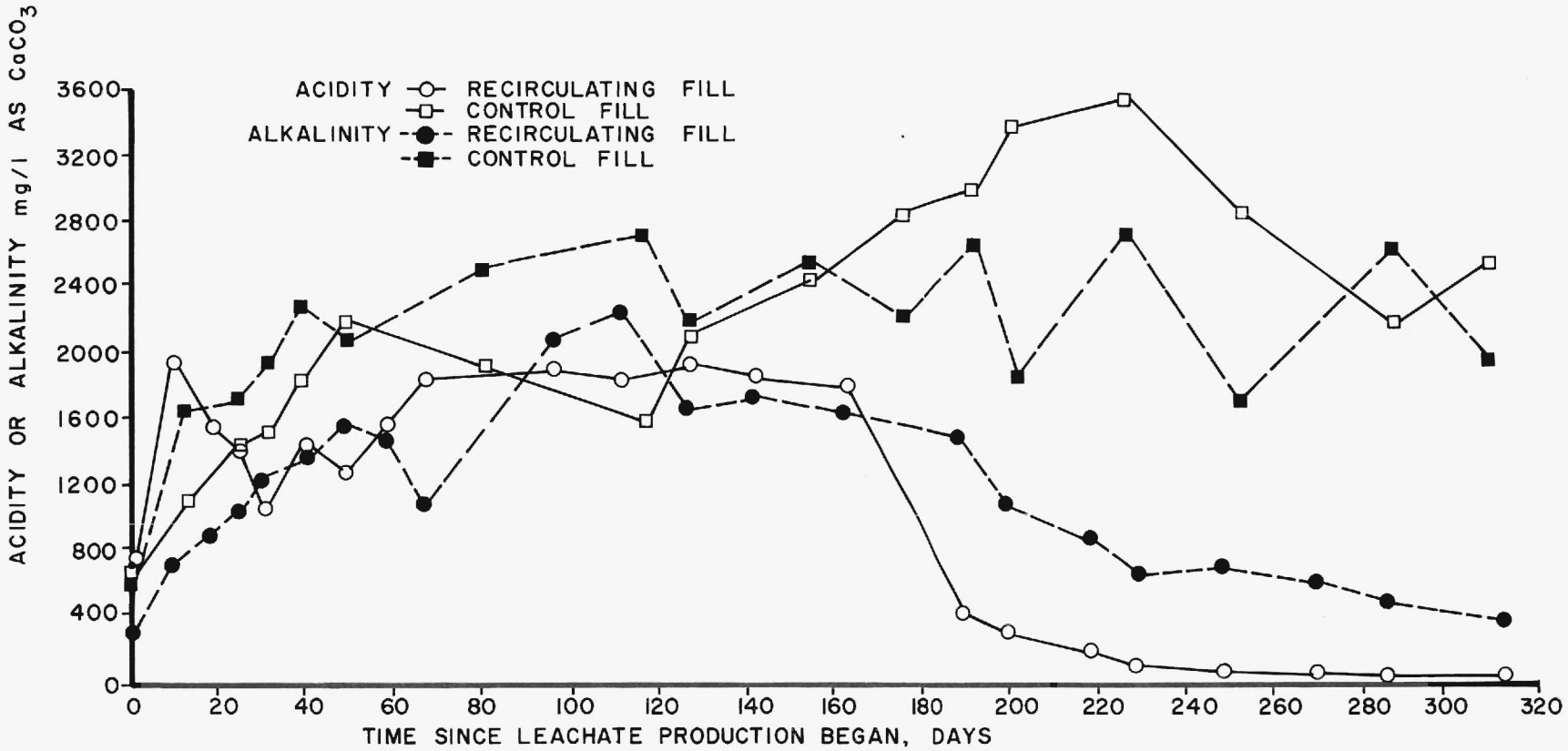


FIGURE 8: ACIDITY AND ALKALINITY OF LEACHATE

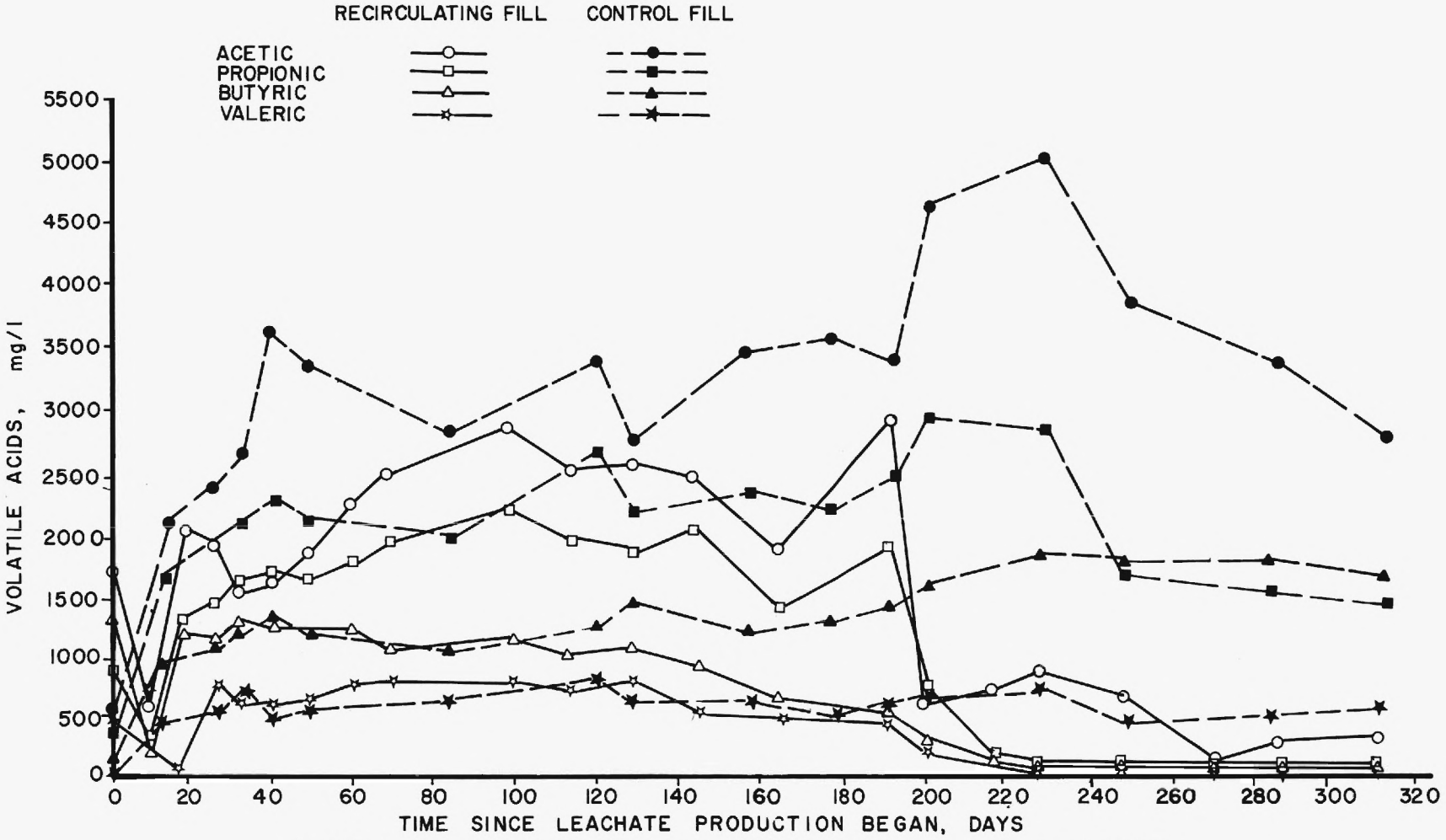


FIGURE 9 : VOLATILE ACIDS CONCENTRATION OF LEACHATE

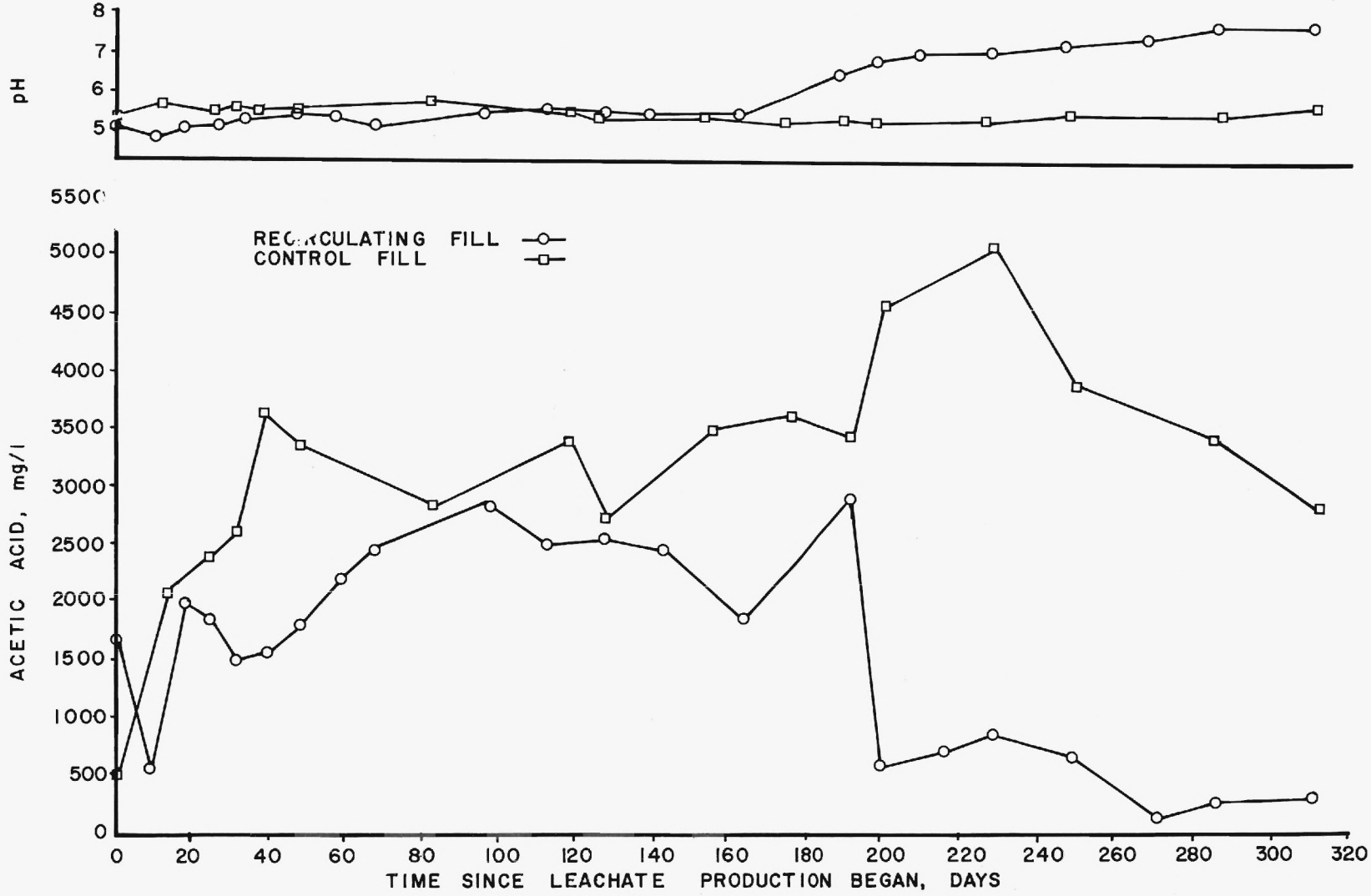


FIGURE 10: PH AND ACETIC ACID CONCENTRATION OF LEACHATE

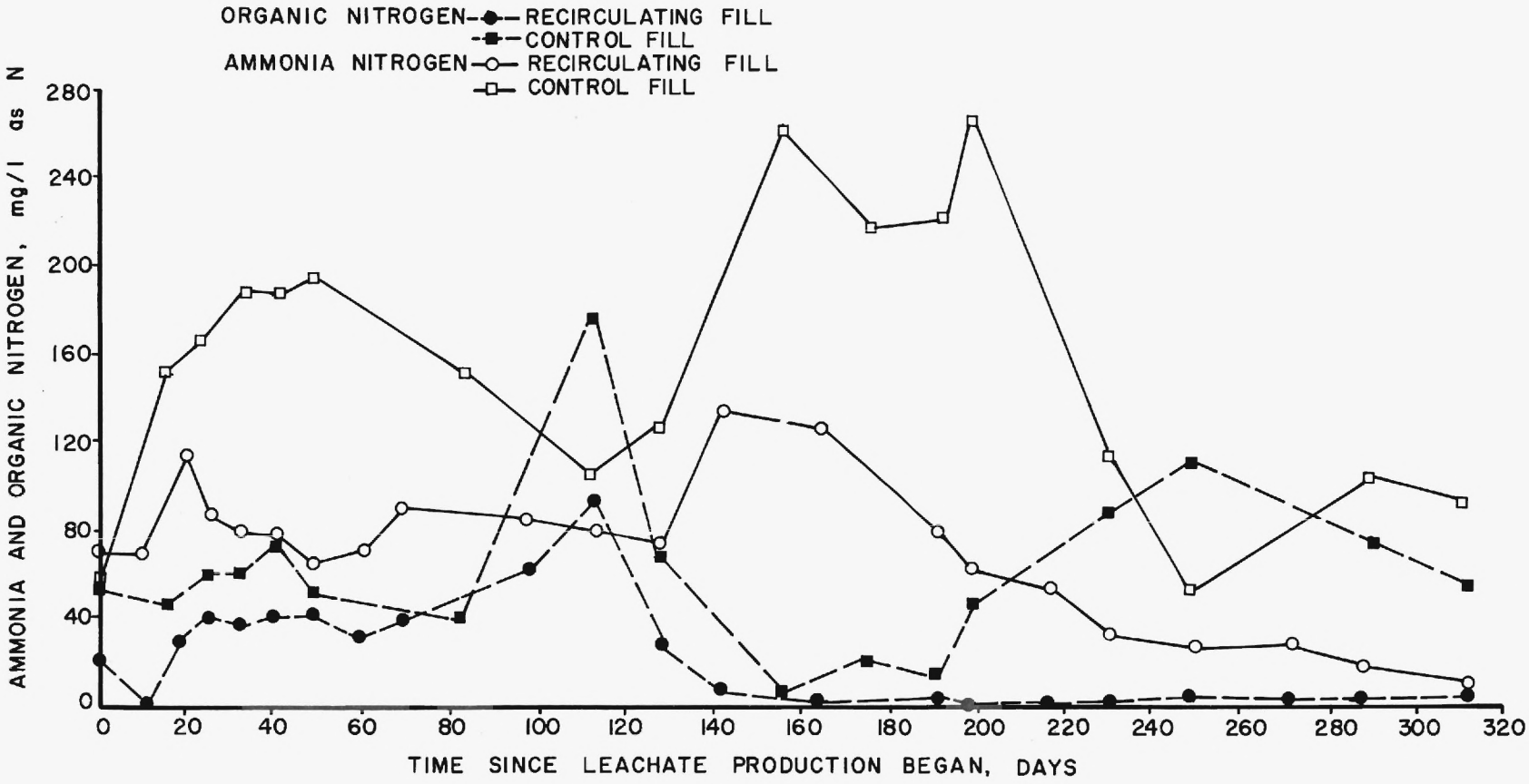


FIGURE II: CONCENTRATION OF ORGANIC AND AMMONIA NITROGEN IN LEACHATE

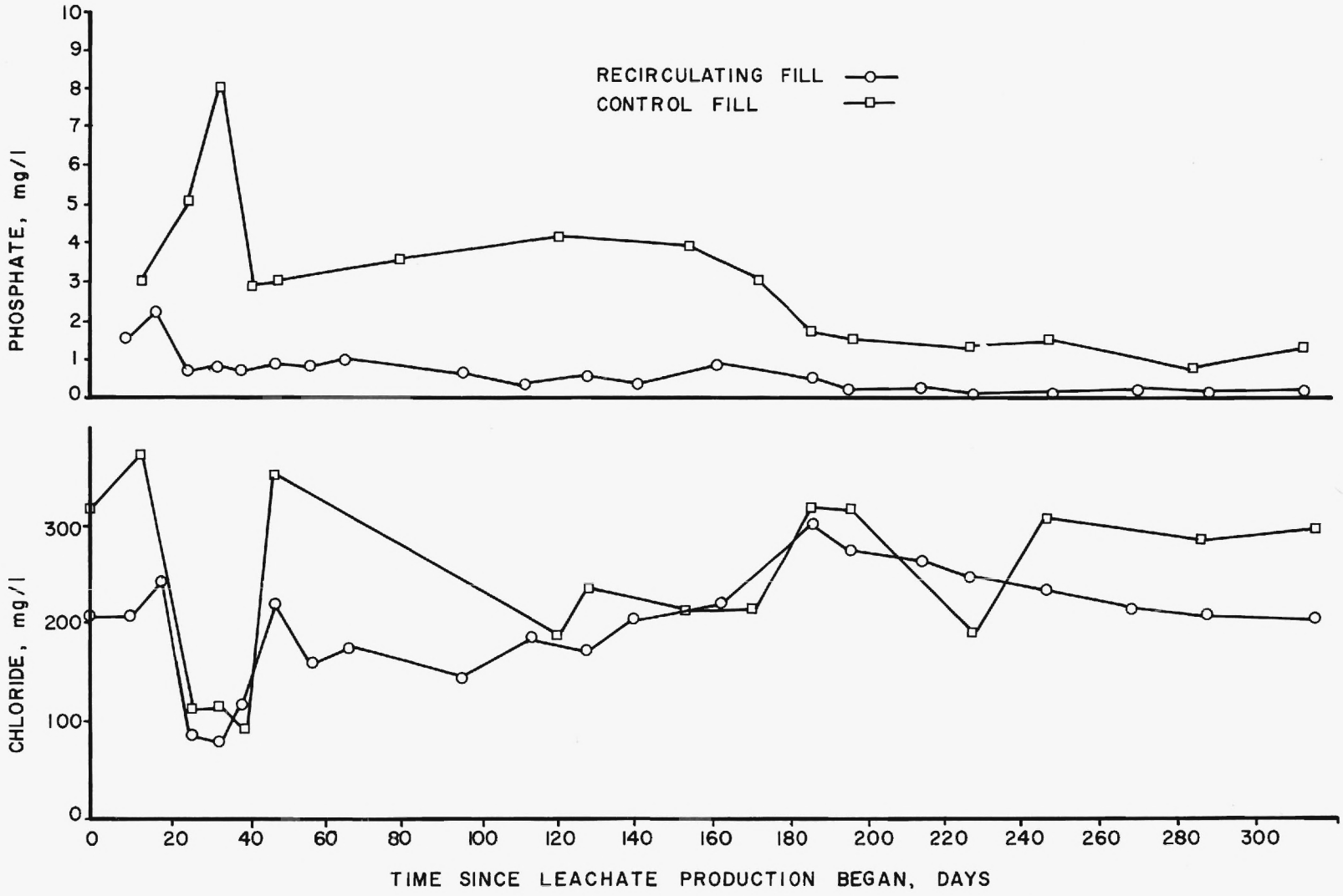


FIGURE 12: CHLORIDE AND PHOSPHATE CONCENTRATIONS OF LEACHATE

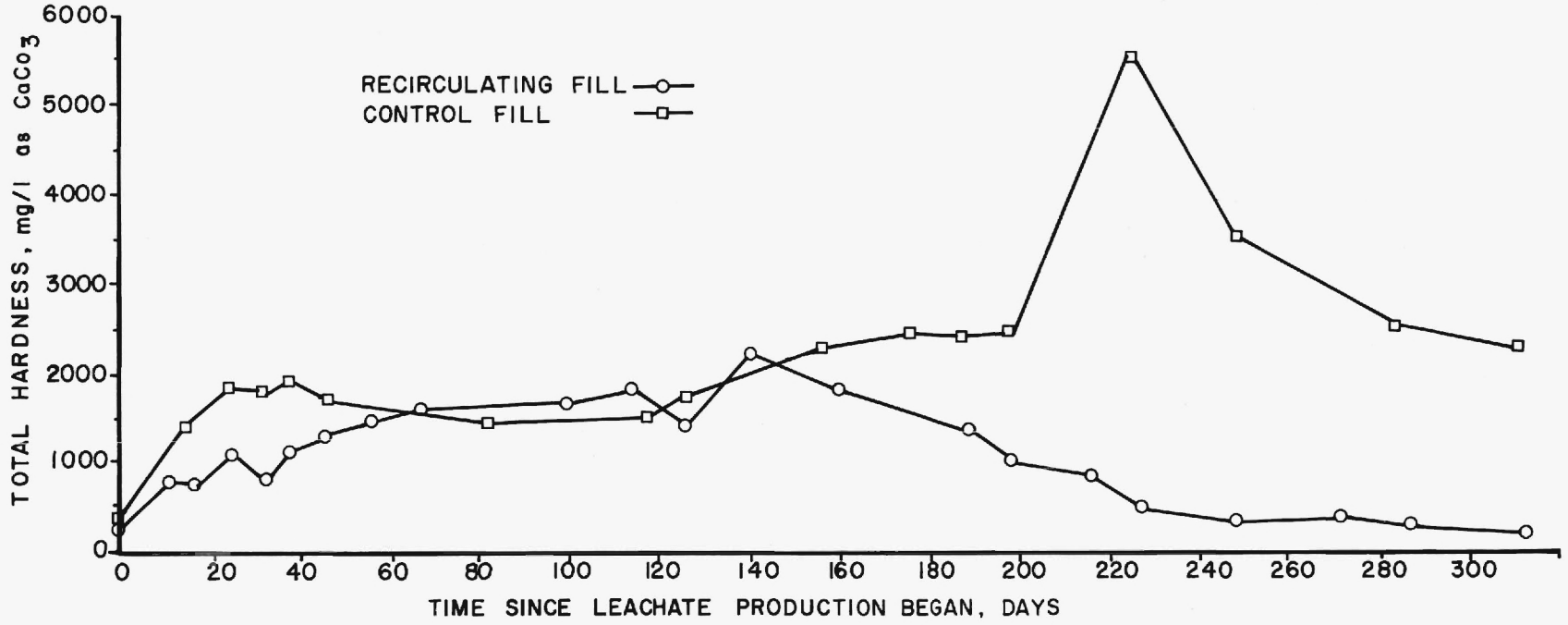


FIGURE 13: TOTAL HARDNESS OF LEACHATE

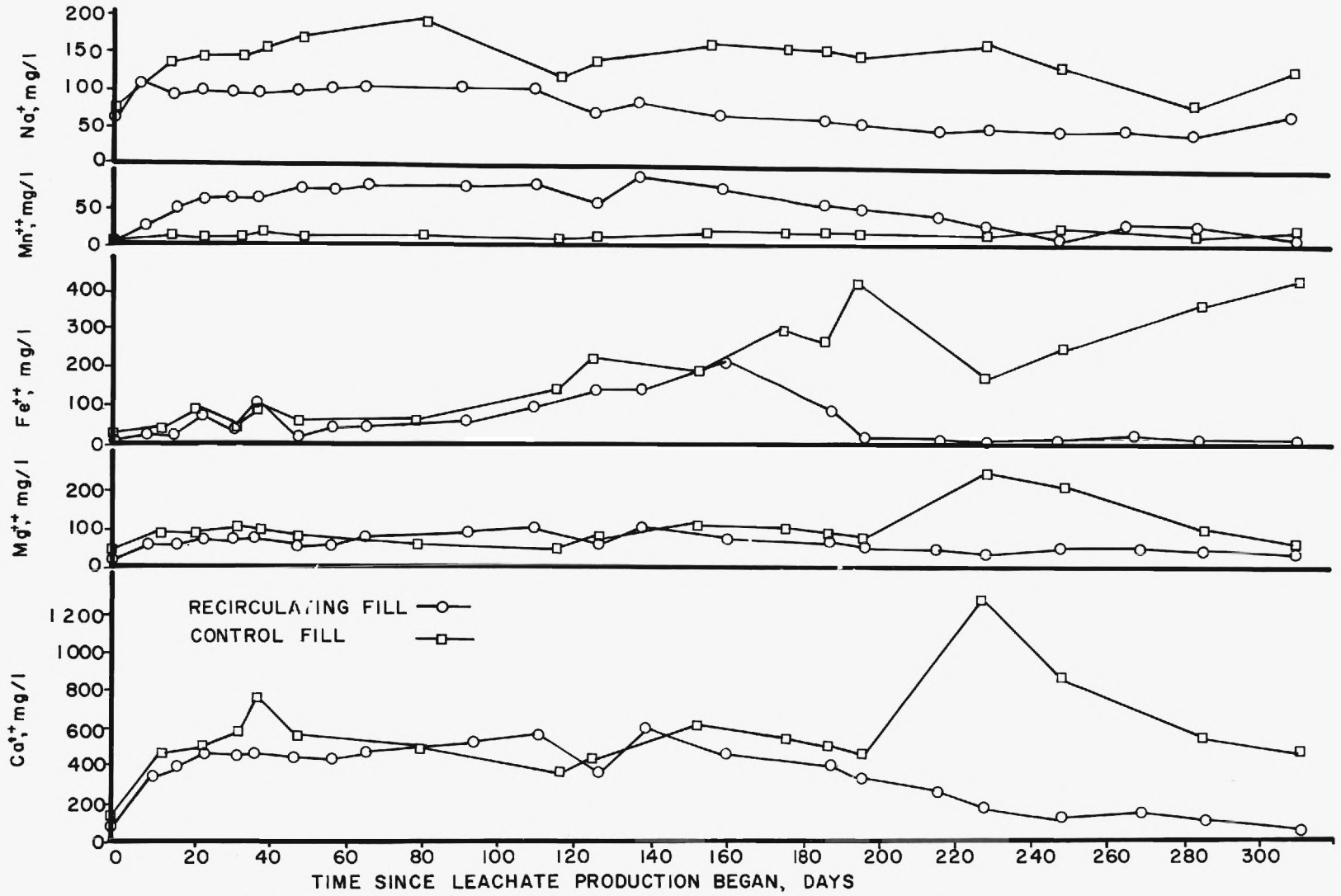


FIGURE 14: METAL CONCENTRATIONS OF LEACHATE

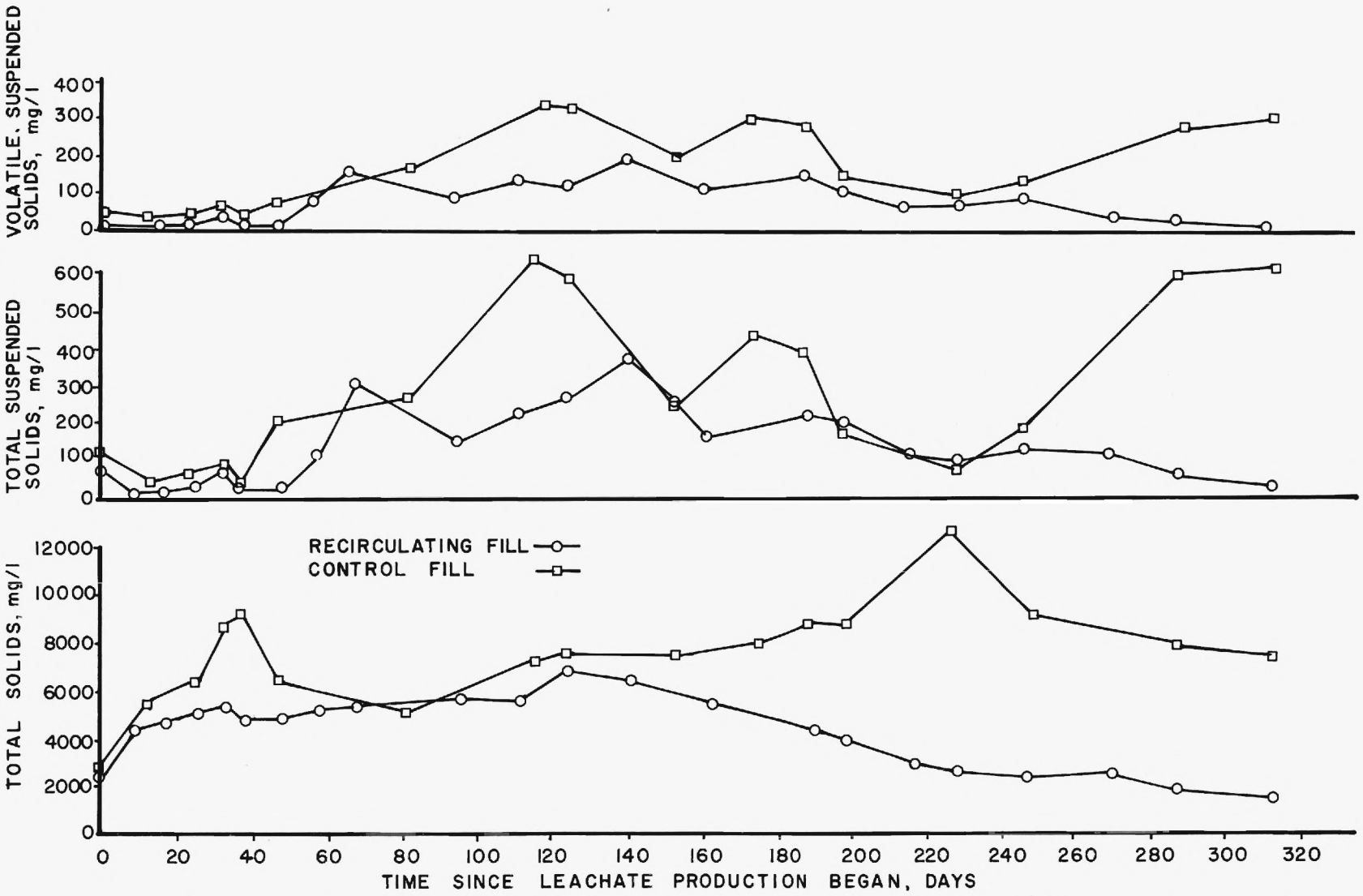


FIGURE 15: SOLIDS CONCENTRATIONS OF LEACHATE

SECTION VII

DISCUSSION

The sanitary landfill method of solid waste disposal depends largely upon anaerobic biological activity to stabilize the decomposable fractions of refuse. The anaerobic process proceeds primarily through two phases with one group of organisms breaking down the larger organic molecules into short-chained organic acids (acid fermentation), and the short-chained acids being subsequently converted to carbon dioxide and methane by another group of organisms (methane formation).

The methane formation phase is generally considered the rate controlling step in the anaerobic process since it proceeds at a much slower rate and requires a higher degree of environmental control than acid fermentation. The greatest majority of methane forming organisms require strictly anaerobic conditions and a near neutral pH. If acid production exceeds the rate of methane formation to an extent greater than the capacity of the system to buffer the acids produced, the pH will drop below the level at which the methane producers can survive and the methane forming phase of the process will cease to function efficiently. In a properly operating anaerobic system, however, the production of volatile acids will rise initially to a peak value and then decrease. Changes in the concentration of the individual volatile acids will also occur. The pH of the system will decrease during the increase in volatile acids and will then rise steadily while the volatile acids diminish.

The effects of leachate recycle on producing a more favorable anaerobic environment in a sanitary landfill were examined for 312 days during Phase I of this study. The significance of the trends observed in leachate quality

and landfill settlement have been discussed as they relate to landfill stabilization and environmental pollution.

Effects of Recirculation on Leachate Quality

The quality of the recirculated leachate reflected a more active anaerobic biological population in the recirculated fill than in the control fill. At the end of the study period the concentration of pollutants were substantially lower in the recirculated leachate.

Volatile Acids and pH

When dealing with an anaerobic system such as a sanitary landfill, the concentration of volatile acids can be one of the most important indicator parameters. These low-molecular weight fatty acids (acetic, propionic, butyric, and valeric) are very diagnostic of the degree of stability of the anaerobic process. Figures 9 and 10 show the behavior of these acids over the study period.

During the first 100 days of the study, the concentration of acetic propionic, butyric and valeric acids increased steadily in both the recirculating and control fills. As was expected, acetic acid was the most abundant, followed by propionic, butyric and valeric. Thus the first step of the anaerobic process was well underway in both fills. However, after this initial rise the volatile acids concentration of the recirculated leachate started to decrease slightly and did so for the next 60 days. Although the pH remained relatively low throughout this period, it was likely that a small population of methane forming bacteria was withstanding the low pH and was preventing the further accumulation of more volatile acids.

After 160 days, the pH of the recirculated fill started to increase and the methane forming step became fully developed. Following a brief rise at 193 days, the volatile acids were reduced quickly. The concentrations of all the

acids were reduced and only acetic remained in measureable amounts at the end of the study period. The pH leveled off at about 7.3, close to the optimum for methane formation and characteristic of a normal biologically mediated environment.

In contrast to the recirculated leachate, the volatile acids continued to increase in the control fill leachate for 220 days. After this period, the acetic and propionic concentrations began to decrease. However, the significance of this decrease in terms of methane formation will require a longer period of study. The pH of the control leachate remained low throughout the study period.

Even though the pH of the system was not controlled, recirculating the leachate produced an environment within the fill suitable for the growth of methane formers, thus allowing the second phase of anaerobic digestion to mature. On the other hand, the control fill environment which was dependent on intermittant rainfall did not encourage the development of a viable population of methane forming bacteria.

Organic Pollution Parameters

Data on the recirculated leachate illustrated in Figures 5, 6, and 7 showed dramatic reduction in all three of the accepted organic pollutional parameters (BOD_5, COD, TOC). The organic content of the control leachate, on the other hand, remained high throughout the study.

The BOD_5 and COD were initially low in the leachate from both fills due to the washing action of the initial water addition. However, by the second week the concentrations of both parameters were higher in the control leachate than in the recirculating leachate. The concentrations in both fills increased until about 140 days at which time the BOD_5 and COD in the recirculated leachate began to decrease steadily. In contrast, the organics in the control leachate

continued to increase for 230 days, showing only a small decrease during the last 90 days of the study. At the end of the 312-day period, the control leachate had COD and BOD_5 values of 13,800 and 8,800 mg/l, respectively, while the recirculated leachate had a COD of 1,280 mg/l and a BOD_5 of 760 mg/l.

The total organic carbon (TOC) generally followed the other organic parameters. The TOC in the recirculated leachate increased for the first 100 days and then decreased for the remainder of the study period. The TOC of the control leachate, however, remained high. The concentration of TOC after 312 days were 2,930 mg/l for the control and 256 mg/l for the recirculated.

At the conclusion of the study all three of the organic pollution parameters showed concentrations in the control leachate which were approximately ten times those in the recirculated leachate. This pattern was similar to that observed for the volatile acids and again emphasized that a more efficient biological stabilization was established in the recirculating fill.

Nitrogen and Phosphate

The concentration of organic and ammonia nitrogen was substantially lower in the recirculated leachate than in the control leachate at the end of the study period. As was the case with the organic pollutants, the initial concentrations of organic and ammonia nitrogen were low due to the initial washing action. After about 100 days the organic and ammonia nitrogen in the recirculated leachate decreased steadily. The organic nitrogen decrease preceded the ammonia decrease as the organic nitrogen was changed to the ammonia form. In the recirculated leachate, at the end of 312 days, less than 10 mg/l of organic nitrogen and only 13 mg/l ammonia nitrogen were found (See Figure 11). As these forms of nitrogen are readily available, the trend indicated a well-developed and more efficient biological activity in the recirculating fill.

The initial phosphate concentrations were very high because the soluble phosphates were leached from the fills by the initial water addition. Subsequently, the phosphate concentrations in both the recirculated and control leachates were low (Figure 12). However, during the study, the phosphate in the control leachate was always greater than that in the recirculated leachate, indicating that the phosphate in the recirculated leachate was being consumed to a greater extent because of the greater biological activity.

Metals and Hardness

For the first 160 days, the concentration of iron was fairly equal in both the control and recirculated leachates. During this period the concentrations increased steadily. However, after 160 days the iron in the recirculated leachate decreased sharply to very low values (Figure 14). This decrease corresponded to the increase in pH from about 5.2 to 7.2. At a pH above about 6 and where much of the stabilization had been completed, the iron began to be oxidized to the insoluble ferric form in a less reducing environment. The ferric form of iron in the recirculated leachate was substantiated by the dark brownish red color of the samples as compared to the light greenish color of the control leachate. Of course, if the control sample was allowed to stand, it soon became brownish red upon the oxidation of its iron content. Thus the great reduction in soluble iron in the recirculated leachate probably resulted from oxidation in the collection sump and brought about by the increase in pH and changeover from a highly reducing to an oxidizing environment. The control leachate, however, which remained at a pH below 6 and was not exposed to air in a collection sump contained rather high concentrations of dissolved iron at the end of the study period.

Although the fluctuations were less pronounced, the concentration of manganese generally followed that of iron. In the early stages of the study period, the manganese was more concentrated in the recirculated leachate which probably reflected a more reducing environment initially in the recirculating fill than in the control fill. That is, the insoluble manganese was being reduced to the soluble manganous form to a greater extent in the recirculating fill. In fact, the soluble manganese in the control leachate remained low (20 mg/l) and relatively constant. As in the case of iron, the concentration of manganese in the recirculated leachate began to decrease (slightly) as the pH started to rise. Unlike iron, however, manganese is relatively soluble up to pH 9 and thus soluble throughout the pH range obtained in the study. It is possible then that the decrease in soluble manganese might have been due to a lessening of the reducing condition within the fill as the refuse approached more complete stabilization.

The concentration of calcium and magnesium in the two fills were approximately equal for the first 200 days (Figure 14). The large rainfall which occurred between 200 and 220 days (See Table 7) washed out a considerable amount of calcium and magnesium from the control fill and thus the concentration in the control leachate increased. The concentrations of these metals in the nonrecirculated leachate was highly dependent on the intensity of rainfall at the fill site.

On the other hand, calcium and magnesium concentrations in the recirculated leachate were not affected by the heavy rainfall. The concentration of magnesium remained fairly constant throughout the study period, decreasing only slightly during the last 160 days. Calcium, however, which was considerably more abundant, showed a more dramatic decrease during the last 160 days. The decreases in calcium and magnesium concentrations might have been due to the

opportunity for ion exchange and for the formation of organo-metallic complexes as the leachate was recirculated through the fill. The exchange and complexation reactions are pH-Eh dependent and thus it would be difficult to predict such reactions from the available data.

The noted decrease in calcium could also have been due to the precipitation of $CaCO_3$ within the fill. Although the pH of the recirculated leachate never reached above 7.4, it is possible that in small isolated pockets within the refuse, the pH could have been sufficiently high to produce calcium carbonate precipitation. For example, such pH values could have occurred in pockets containing ammonia. As the pH rose from 5.5 to 7.4, it became less likely that such precipitated carbonate was redissolved as the leachate perculated through the fill. Consequently, the effect of the recirculation on the calcium and magnesium content of the leachate was not totally clear probably due to a combination of washing action and exchange, complexation, and precipitation reactions.

The total hardness in the leachate, of course, followed the trends of the divalent cations. Decreases in calcium and ferrous iron in the recirculating leachate corresponded to decreases in hardness to a final value of 377 mg/l as compared to the relatively high 2,229 mg/l found in the control leachate (See Figure 13).

Acidity and Alkalinity

Figure 8 shows the behavior of acidity and alkalinity for the control and recirculating leachates. The predominant source of acidity in the system was the organic volatile acids and thus the leachate acidity followed closely the trends associated with these acids as substantiated by a comparison of Figure 8 and Figure 9. At the end of the study period, the acidity of the recirculated leachate had decreased to 80 mg/l, whereas the acidity of the control

leachate remained rather high at 2,400 mg/l.

In anaerobic processes, the alkalinity is due to an association of anions with cations with the carbon dioxide-bicarbonate-carbonate system prevailing at neutral pH and the acetate, etc. system prevailing at low pH. Ammonia and/or calcium often serve as the principle cations. When comparing Figure 8 with Figures 11 and 14, alkalinity in both leachates followed the trends of ammonia and calcium. As the pH of the recirculated leachate increased and the ammonia nitrogen and calcium ion concentration decreased, the alkalinity of the system decreased. The alkalinity of the control leachate, however, remained high throughout the study and showed extreme fluctuation from sample to sample probably attributable to the influence of intermittant rainfall. The alkalinity in the recirculating leachate as well as the ammonia nitrogen was lower than that of the control leachate throughout the study again due to the influence of dilution and other reactions as stated previously.

Solids

Although it was difficult to attach meaningful interpretation to the solids data because of its dependence on various uncontrollable physical and chemical processes, it was important to note that at the end of the study period the total solid content of the recirculated leachate was much lower than that of the control leachate; 1,627 mg/l and 7,167 mg/l respectively (See Figure 15). As was true with most of the measured parameters, the decrease in solids in the recirculated leachate corresponded to the increase in pH and the increased stability of the leachate.

It was clear from the parameters measured, that recirculation of leachate through a sanitary landfill dramatically improved the quality of the leachate, in terms of reduction in organic pollution load and, to a lesser extent, the

inorganic load, in a fairly short period of time.

Effects of Leachate Recirculation on Landfill Settlement

The recirculation of leachate greatly increased the rate of surface settlement in the simulated landfill. Measurements on the cumulative surface settlement of the recirculating fill presented in Table 6, indicated a much faster rate of settlement than in the control fill. The total surface settlement for the control fill was 1.070 feet while the recirculating fill settled 1.51 feet during the same period. The increased surface settlement was attributable to an accelerated rate of biological stabilization and mechanical settling and/or compaction due to the recirculation of leachate through the fill.

The cumulative settlement which occurred during the first six days was probably due to the physical compaction by the water applied; biological stabilization was primarily responsible for the settlement thereafter. During the first six days, surface settlement of the recirculating and control fills was 1.21 and 0.790 feet respectively. Rainfall during the same period (Table 7) was 5.161 inches (0.86 inches/day) which easily accounted for the control fill settlement, and, when superimposed on the recirculation rate, explained the settlement of the recirculating fill. Both fills remained at the height observed on the sixth day for some time; however, the recirculating fill began settling again seven days earlier than the control and proceeded at a more rapid rate.

Effects of Leachate Recirculation on Landfill Stabilization

The quality of the recirculated leachate and the increased settling rate observed for the recirculating fill emphasized the fact that a more active anaerobic biological system was established and operated in the recirculating fill.

A comparison of the initial refuse composition with the composition of samples taken from the fills at the end of the study supported the fact that anaerobic decomposition and thus stabilization of the organic portion of the refuse had proceeded further in the recirculating fill than in the control fill. At the end of the study, the sampled refuse from the recirculating fill had experienced a 21.6 percent reduction in organic carbon and a 25.9 percent reduction in volatile solids. The control fill refuse, on the other hand, had experienced only a 2.5 percent reduction in organic carbon and a 7.9 percent reduction in volatile solids (See Table 4). The samples, at the end of the study, were taken from near the surface of the refuse and probably do not reflect as great a decomposition as refuse from the center of the fill would. It was found that, because of refuse compaction and pipe corrosion, it was impossible to obtain refuse samples from the 0.5 in. GVS ports that had been installed in the Phase I units. However, it is clear from present data that stabilization was being accomplished faster in the recirculating fill than in the control fill.

As discussed previously, the volatile acid concentrations in the recirculated leachate decreased dramatically after about 200 days of recirculation. The rapid decline in volatile acids caused a concomitant rise in pH. It was noted that the pH rose quickly from 5.2 to 6.6 and then rose steadily to a high value of 7.4. Thus the pH of the system quickly came within the optimum range (6.6-7.4) for the pH sensitive methane-forming bacteria. As the methane forming phase became established, a stable anaerobic system was produced within the recirculating fill. Because the stabilization of refuse in a sanitary landfill is dependent upon anaerobic biological action, the stable anaerobic system in the recirculated fill naturally promoted the stabilization process. In contrast,

the environment within the control fill never reached pH values suitable for the establishment of a methane-forming population and thus, during the study period, the control fill never became stabilized to the extent of the recirculation fill.

The dramatic reduction in BOD_5 of the leachate by recirculation through the fill supported the hypothesis that recirculation increased the rate of refuse stabilization. The BOD_5 of the recirculated leachate by the end of the study period was reduced 92 percent from its maximum value. The nonrecirculated leachate showed only a 34 percent reduction from its maximum BOD_5 over the same period. Thus in terms of readily biologically oxidizable organics in the refuse, the recirculating leachate produced a much greater degree of refuse stabilization.

Also as previously discussed, the rate of surface settling in a sanitary landfill could be partially attributed to stabilization processes within the fill. In comparison to the surface settlement of the control fill, it was clear that leachate recirculation increased the rate of refuse stabilization.

Because ultimate site use is one of the primary concerns when designing a sanitary landfill for solid waste disposal, the rate of refuse stabilization is most important. The ultimate use of many landfill sites must be delayed for years because of continuing settling, gas release, etc. It appears, however, that when recirculation of leachate is practiced, refuse stabilization may be approached in a much shorter period of time. Because the value of the landfill site, in terms of ultimate use, may be realized sooner, economic conditions may well warrant recirculation on a large scale.

Effects of Recirculation on Total Environmental Pollution

Based on the leachate production of the control fill presented in Table 9, the total mass of material leached from the control fill during the 312-day test

period was calculated. The total mass of materials present in the recirculated leachate at the end of the study was also calculated using the same volume of leachate as was produced by the control fill. The mass of the various materials was tabulated in Table 11.

A comparison of the quantities after the 312 days indicated that a large quantity of the material extracted was attenuated by the anaerobic biological system established in the recirculating fill. From Table 11, the 54.1 gallons of recirculated leachate after 312 days could be released to the environment with much less total consequence than would be the case with the nonrecirculated leachate. It follows that, if the leachate from a landfill is contained and recirculated until refuse stabilization is near completion, it can be released to the environment more predictably and with a much less pollutional effect than leachate from conventional nonrecirculating fills.

In many areas where ground water is used for drinking water supplies, the sanitary landfill disposal method has been discouraged because of possible leachate contamination. When landfills are used in these areas, the leachate must be collected, treated and discharged to receiving waters. Since the leachate is extremely high in BOD_5 as well as some inorganics, it could severely tax a municipal treatment facility and especially a small private facility. In light of the present data, this problem may be alleviated by recirculating the collected leachate back through the fill by a series of pumps and distributor pipes. As each cell of the fill is completed, the recirculation system could be installed. The leachate could then be recirculated until stabilization of the fill was approached or until the BOD_5 or other pollutional parameters are reduced to levels such that the leachate is amenable for discharge or for release to additional treatment depending on the condition of the receiving waters. In essence, the landfill itself is thereby used as an anaerobic

Table 11

Quantities of Materials Leached from the Control Landfill and Present in the Recirculated Leachate after the 312-Day Study Period

Leachate Constituent	Quantity of Material, lbs.	
	Recirculating Fill*	Control Fill**
COD	0.55	3.44
BOD_5	0.34	2.29
TOC	0.11	0.84
TSS	0.14	0.39
VSS	0.008	0.044
TS	0.73	2.11
Alkalinity as $CaCO_3$	0.31	0.56
Acidity as $CaCO_3$	0.04	0.52
Total Hardness as $CaCO_3$	0.17	0.51
Acetic Acid	0.16	0.72
Propionic Acid	0.05	0.33
Butyric Acid	0.02	0.19
Valeric Acid	nil	0.38
Phosphate as $PO_4^=$	nil	0.0072
Organic Nitrogen as N	0.003	0.028
Ammonia Nitrogen as N	0.014	0.046
Chlorides as Cl^-	0.09	0.139
Calcium	0.04	0.14
Magnesium	0.017	0.022
Manganese	0.004	0.0024
Sodium	0.03	0.044
Iron	nil	0.029

*Based on a total volume of 54.10 (same as total leachate production in control fill) gallons and the concentrations at end of study period.
**See Table 8 for leachate volumes.

treatment system.

Assuming that the simulated landfills used in the study can be related to large-scale landfill operations, it appears that recirculated leachate can reach, in a reasonable length of time, a quality suitable for release into noncritical receiving waters. Whether such inorganic pollutants as hardness, chloride, etc. require additional treatment depends entirely on the condition of the receiving waters and/or regulatory requirements.

It would also be possible to use leachate recirculation in combination with external treatment. Since most landfill sites are not near municipal sewerage systems, it would be advantageous to use portable package waste treatment plants at the site. However, such plants are not suitable for the treatment of leachate from a conventional landfill because intermittant leachate flow is not conducive to successful operation of such a system. By recirculating the leachate through the portable plant and through the landfill, a constant flow could be maintained and adjusted to suit the capacity of the plant. The plant effluent could be discharged intermittantly to the receiving waters at the most advantageous times. When the landfill became stable (time to reach stability reduced by leachate recirculation) the portable plant could be moved to another location.

Leachate recirculation can be applied to any landfill site regardless of its location and result in a decrease in time required for refuse stabilization. This fact may be very important in dry climates where, due to lack of sufficient moisture, landfills may take hundreds of years to reach complete stabilization.

The primary importance of leachate recirculation is that quantities of organic pollutants, and to some extent inorganic pollutants, released to the environment will ultimately be less than from a freely-leaching landfill.

Research Continuation Procedures

The data collected to date have shown that leachate recirculation will increase the rate of landfill stabilization, reduce the concentration of pollutants in the leachate, and permit ultimate and controlled discharge with or without additional treatment. Continuing research should be initiated to determine if the leachate from the control fill will reach the quality attained in the recirculating leachate after approximately one year.

The Phase II simulated landfills will be operated to determine the effect of pH control and nutrient addition on the stabilization process. The larger ports installed on these units will facilitate the periodic sampling of the refuse. Also, provisions have been made for the sampling of any gas which may be released by the anaerobic biological processes. Both units will have leachate pH control and one unit has had sludge added to the refuse for nutrients and/or seeding.

SECTION VIII

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FOREWARD

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SUMMARY

Sanitary landfill stabilization is largely dependent upon biological activity for decomposition of available organic materials. The results of Phase I of this study indicated that the recirculation of leachate through the fill material in a column-type simulated landfill can result in a higher rate of stabilization of the compacted refuse, a controlled retention and treatment of many pollutants in the leachate, and a reduction in the total pollutional load potentially discharged to the environment by leachate from conventially designed sanitary landfills.

Results from Phase II of this study indicated that recirculation of the leachate aided by neutralization by pH control accelerated the rate of stabilization of the compacted refuse, and also reduced, to a greater degree, the total pollutional load potentially discharged to the surrounding environment. The results also indicated that seeding with raw primary sewage sludge accelerated the decomposition process to the extent that acid production was exceedingly rapid and an initial deterrent detrimental to methane fermentation, without adequate pH control. Recirculation with pH control reduced the time required for stabilization without pH control by about one half. Consequently, time for stabilization of the readily available organics was reduced from about one year to six months.

CHAPTER 1

REVIEW OF THE LITERATURE

Whenever refuse is deposited on land, some of its organic and inorganic constitutents are subject to leaching as water percolating through the refuse carries these materials into aquifers, surface streams or impoundments. Such leaching of pollutants may seriously impair water quality and endanger the health and welfare of the community.

The leachate formed by such action has been defined as the contaminated liquid which is discharged from a landfill to either surface or subsurface receptors[1]. For pollution of ground water to occur, three conditions are required: (1) the refuse must be located over, adjacent to, or in an aquifer; (2) supersaturation must exist in the fill due mainly to the movement of ground water into the fill and percolation of precipitation and surface water runoff; and, (3) leached fluids must be produced and this leachate must be capable of entering an aquifer[2].

A review of the effects of leachate on water quality; quantities and characteristics of leachate produced by landfills (a compilation of the various parameters is presented in Table 1); parametric considerations of landfill stabilization; and, landfill design and operational criteria were presented in a Special Research Project report by Maye[3].

Effect of pH Neutralization on Anaerobic Processes

The pH of an anaerobic process is reflected by the relationship between the volatile acids, alkalinity, and carbon dioxide in the gas produced[4]. The optimum pH for the process as determined by studies on

Table 1
Variations of Leachate Composition

Analysis*	1	2	3	4	5	6	7	8	9		10	11	12	13	14		15	16	17
pH	5.6	5.9	8.3	-	-	-	-	-	7.63	5.60	7.4	6.4	4.9	5.6	8.4	5.7	6.3	6.48	5.88
Total Hardness (as $CaCO_3$)	8,120	3,260	537	-	8,700	500	900	290	8,120	650	-	-	2,500	30	-	-	7,600	13,100	10,950
Total Alkalinity (as $CaCO_3$)	8,100	1,710	1,290	-	-	-	-	-	9,520	730	-	-	-	-	9,450	100	10,630	16,200	20,850
Total Iron	305	336	219	1,000	-	-	40	2	305	6	-	206	152	28	-	-	175	546	860
Sodium	1,805	350	600	-	-	-	-	-	1,805	85	-	1,200	1,100	300	-	-	584	1,428	1,439
Potassium	1,860	655	-	-	-	-	-	-	1,860	28	-	-	920	110	-	-	1,050	2,535	3,770
Sulfate	630	1,220	99	-	940	24	225	100	730	248	248	940	970	65	-	-	615	1,002	768
Chloride	2,240	-	300	2,000	1,000	220	-	-	2,350	90	1,845	1,100	1,600	485	12,300	280	951	2,000	2,310
NO_3-N	-	5	18	-	-	-	-	-	-	-	-	-	196	10	-	-	-	-	-
NH_3-N	845	141	-	-	-	-	160	100	845	0.2	668	-	-	-	-	-	473	756	1,106
TON	550	152	-	-	-	-	-	-	550	2	101	-	-	-	-	-	288	664	1,416
COD	-	7,130	-	750,000	-	-	3,850	246	-	-	-	35,700	21,120	282	-	-	-	-	-
BOD	32,400	7,050	-	720,000	-	-	1,800	18	33,100	81	5,491	-	-	-	7,330	5.9	14,760	26,940	33,360
TDS	-	9,190	2,000	-	11,254	2,075	-	-	-	-	-	11,254	15,830	1,740	-	-	-	-	-
Specific Conductance	-	-	-	-	-	-	3,000	2,500	-	-	-	-	-	-	-		-	-	-

*All Analyses in mg/l except pH and specific conductance.

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5. From reference 15, (3 year old fill).
6. From reference 15, (15 year old fill).
7. From reference 16,(New fill).
8. From reference 16,(Old fill).
9. From reference 17, (Maximum and minimum).
10. From reference 18.
11. From reference 19,
12. From reference 1,(Site A).
13. From reference 1, (Site B).
14. From reference 20,(Maximum and minimum).
15. From reference 21, (Cylinder A, maximum).
16. From reference 21, (Cylinder B, max.)
17. From reference 21, (Cylinder C, maximum).

wastewater sludge has been reported in the 6.8 to 7.2 range, with the limits of operation without significant inhibition being 6.6 to 7.4[5-8].

Dague[4] has reported that lime, sodium bicarbonate, sodium hydroxide, potassium hydroxide, and ammonia may be used for pH control during digestion with other bases probably suitable if evenly fed to the digester contents. In addition, the quanity introduced into the system for neutralization should not cause cation toxicity.

Published results concerning the toxicity of light metal cations on the anaerobic digestion process by McCarty[9] and Kugelman and Chin[10] indicated that alkali and alkaline-earth cations can be moderately inhibitory at certain ranges of concentration (See Table 2). A concentration defined as moderately inhibitory was one which normally could be tolerated, but required some acclimation by the microorganisms. When introduced suddenly, the concentrations could be expected to retard the process significantly for periods ranging from a few days to over a week. Also presented in Table 2 are ranges where the cations are stimulatory and strongly inhibitory.

Table 2[9]

Stimulating and Inhibitory Concentrations of Alkali and Alkaline-Earth Cations to the Digestion of Sewage Sludge

	Concentration, mg/l		
Cation	Stimulatory	Moderately Inhibitory	Strongly Inhibitory
Sodium	100-200	3500-5500	8000
Potassium	200-400	2500-4500	12,000
Calcium	100-200	2500-4500	8000
Magnesium	75-150	1000-1500	3000

Similarly, Kugelman and Chin[10] found that the toxic upper limit for cation concentrations was 6900 mg/l for sodium, 5100 mg/l for potassium, 6000 mg/l for calcium, and 1580 mg/l for magnesium.

Dague[4] emphasized that the addition of any chemical to a digester in order to raise the pH is only a temporary, holding action, and that such measures will not correct the basic cause of the imbalance in methane formation, but will only delay adverse effects until the problem is corrected. One adverse effect would be the creation of an acidic environment in which methane production ceases and the methane forming bacteria are greatly reduced. In 1954, Sawyer, et al.[11] concluded that, "since it is known that raw sludge is deficient in buffering capacity, that highly buffered materials are most resistant to changes in pH, and that natural buffers in digesting sewage sludge consist largely of calcium, magnesium and ammonium bicarbonate, it seems reasonable to conclude that the judicious addition of lime to neutralize organic acids in order to maintain favorable pH values, will result in a desirable climate for methane formers, thereby allowing normal digestion to progress and at the same time adding to the total buffering capacity of the system". A similar effect could be anticipated for sodium hydroxide neutralization which was the chemical used in this study to buffer the anaerobic system created within the simulated landfills as reported initially by Breland[12].

CHAPTER II

MATERIALS AND METHODS

Simulated Landfill Construction

Since the purpose of the research was to develop and study the feasibility of a leachate recycle system to provide leachate treatment and pollution control as well as accelerated rates of biological stabilization within sanitary landfills, four simulated landfills were constructed on the campus of the Georgia Institute of Technology in Atlanta, Georgia. The construction was accomplished in two phases. The two fills of Phase I were completed in the spring of 1971; the two fills of Phase II were completed in the spring of 1972. All four similated landfills were basically similar except for a few modifications during Phase II.

Phase I

The purpose of the initial phase of the study was to demonstrate the advantage of leachate recycle in accelerating the stabilization of sanitary landfills and in removing readily degradable pollutants from the leachate. Two simulated landfills were constructed, one as a control without recirculation, the other with recirculation capabilities.

The fills consisted of two sections of 36-inch diameter ARMCO corrugated steel pipe which were joined together to provide a total height of 14 feet. A conical concrete bottom facilitated drainage and collection of the leachate into sumps composed of 55-gallon drums. A detailed plan of the simulated landfills is shown in Figure I.

Leachate from the control fill, Fill 1, was collected in a drain line which was kept sealed except during sample collection. The leachate collected from the recirculating fill, Fill 2, was removed from the sump and pumped back

through a distributor buried between the top of the compacted refuse and the soil cover and allowed to percolate through the refuse (See Figures 1 and 2).

Three ports of 0.5-inch GVS pipe were installed in each fill; two for refuse sampling, the third contained a temperature probe. Ten feet of compacted simulated refuse were placed in each of the landfill colums. The composition indicated in Table 3 was chosen to reflect that of a typical municipal refuse. A total of 2,800 pounds of refuse was placed at a dry density of 535 lb./cu.yd.

Table 3

Composition of Simulated Refuse

Constituent	Dry Weight, Percent
Paper	50.0
Plastic	3.0
Glass	7.0
Garbage	25.0
Rags	5.0
Stone and Sand	5.0
Metal	4.0
Wood	1.0
	100.0

After an initial settlement of six inches in two weeks, a soil cover of 30 inches was placed on the refuse to bring the total height to 12 feet. To expedite the production of leachate, 250 gallons of tap water were added after the placement of the compacted soil cover. This amount was added in a 12-hour period and some initial short-circuiting did occur. A more detailed account of the construction of the simulated landfills and experimental procedures during Phase I is presented by Maye[3].

Phase II

The purpose of the second phase was to illustrate the effects of re-circulation plus nutrient addition and pH control on the stabilization of

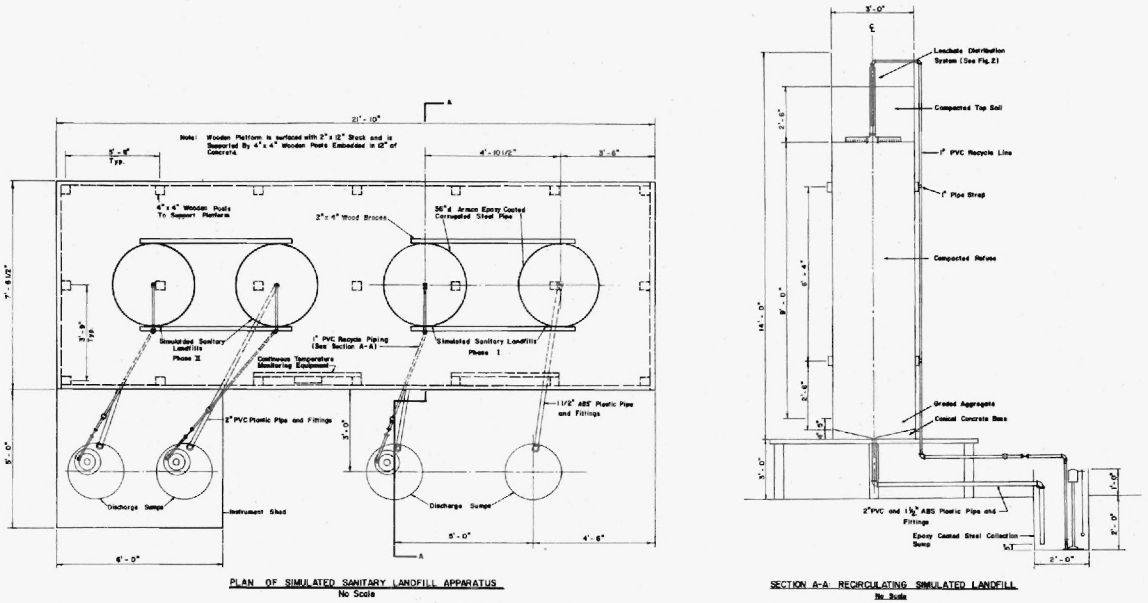

Figure 1: Plan of Simulated Landfill Apparatus.

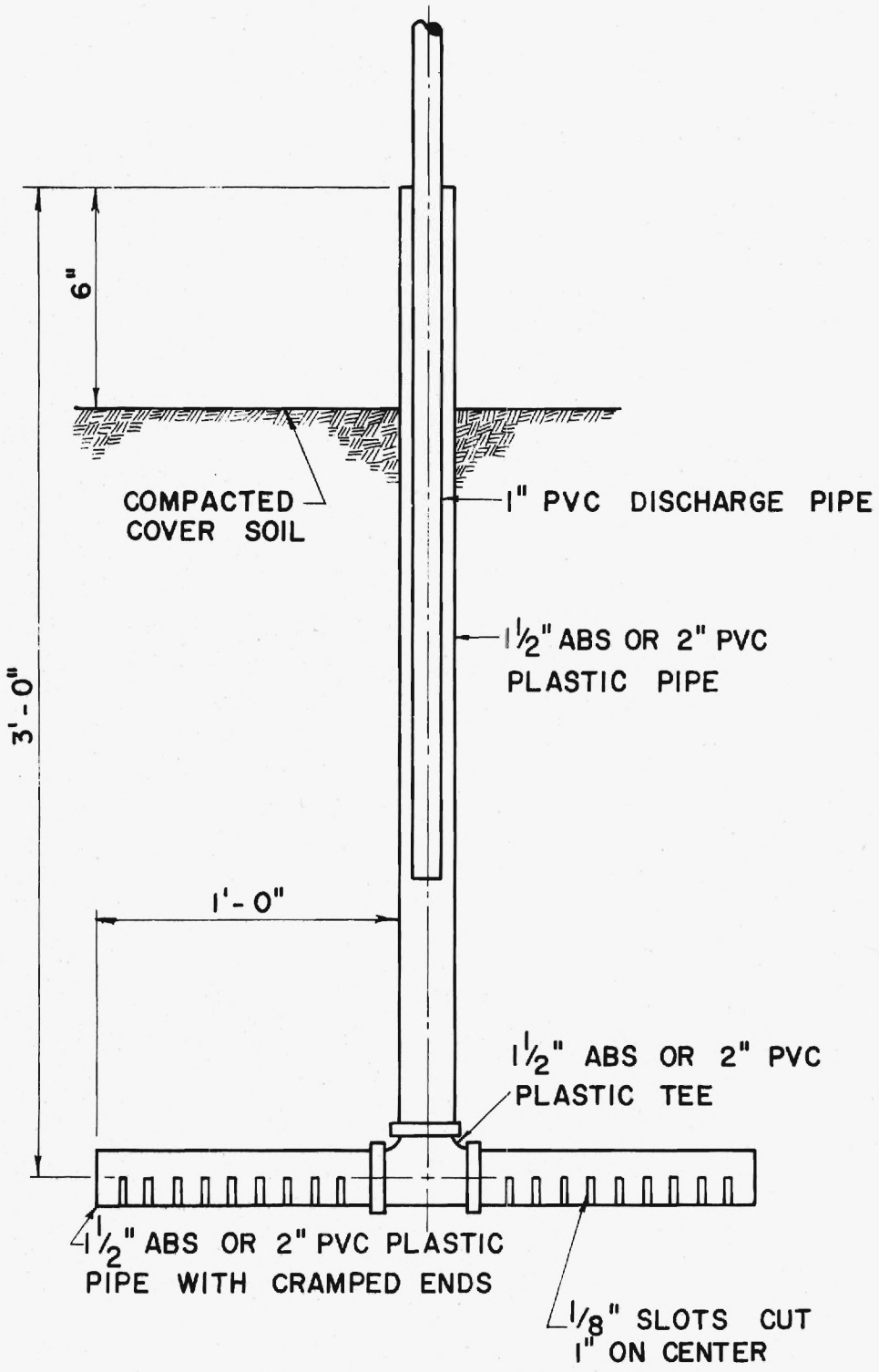

FIGURE 2: LEACHATE DISTRIBUTION SYSTEM

sanitary landfills. Therefore, two additional simulated landfills were constructed with recirculation capabilities. Because these units were completed approximately one year after construction of the initial two fills, it was possible to initiate some minor improvement.

The basic columns in Phase II were identical to those in Phase I (see Figure 1). However, the leachate drains in the conical concrete bases were changed from 1.5-in. ABS to 2.0-in. PVC pipe. The drains from each column discharged into 55-gallon drums which were equipped with polypropylene liners to provide a more corrosion resistant container. The sumps for both fills were housed in a metal building (5' x 6') which provided cover and also served as an instrument shed. Recirculation was provided as before except that the distribution pipe (See Figure 2) was increased in diameter from 1.5-in. to 2.0-in. This provided more volume and thus reduced the chance of leachate overflowing the distributor system.

The refuse used in the Phase II units had the same composition (by weight) as that used in Phase I (See Table 2). The refuse was coarsely chopped and placed in the columns. The refuse was manually compacted in three 3.3-ft. lifts to a dry density of about 535 lb./cu.yd. In one fill, Fill 4, 10 gallons of primary sewage sludge were added after each lift and an equal volume of tap water was added to the other column, Fill 3.

To prevent clogging, the distributer was separated from the top of the refuse by a 3-in. layer of coarse gravel (1 to 3-in.). Two feet of soil with a sod cover similar to that used on the initial two fills were added immediately to each unit and rainfall was not excluded. In order to bring the fills up to field capacity, 220 gallons (30 gallons previously added by sludge and water) of tap water were added. In an attempt to minimize short-circuiting, the water was added over a 72-hr. period.

To facilitate the collection of representative refuse samples at periodic intervals, two sampling ports were installed on each of the new columns. The ports were constructed by placing a section of 3-in. ABS plastic pipe through the sides of the columns. The pipes were equipped with threaded plugs and all joints and connections were caulked with sealing compound.

In each new fill, a 0.75-inch PVC pipe was placed to a depth of five feet below the sod layer along the side of the corrugated metal pipe. To this pipe was connected a rubber hose which was bent into a large beaker of water. The purpose of this pipe-hose-beaker apparatus was for the collection and analysis of any gas that might be produced (See Figure 3). Additional information concerning the construction of the two fills and their operation has been presented previously by Breland[12].

Sampling Procedures

Phase I

A 24-hour sample was taken from the recirculating simulated landfill at one to three-week intervals. An Instrumentation Specialties Company Model 780 Automatic Sample Collector was used to collect 24, 560-ml samples which were composited at the end of the sample period. A 1.0-liter aliquot was taken from the composite for analysis. The remainder of the composite was initially discarded due to the large quantities of leachate collected from the recirculating fill, however, after 30 days of sampling, residual samples were returned to the collection sump.

Samples were obtained from the non-recirculating control fill whenever a sufficient quantity of leachate was produced from rainfall to yield a sample of one to three liters. When a sufficient volume of leachate had collected in the base of the control fill, the drain line was unplugged and the leachate allowed to flow into a clean container. The line was again plugged

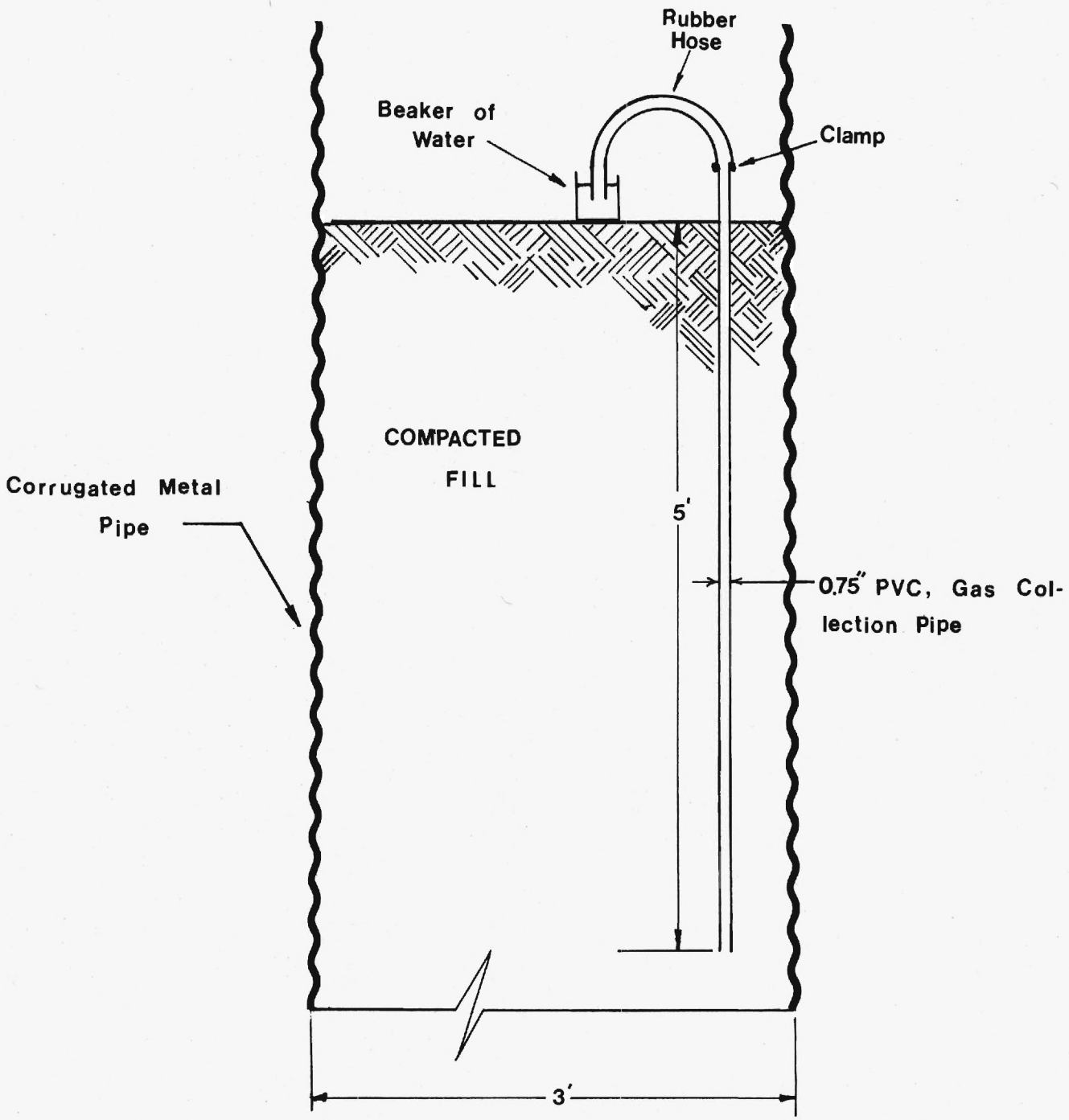

FIGURE 3: CROSS SECTION OF PHASE II GAS SAMPLING APPARATUS

after all the leachate had been collected.

Phase II

Samples collected during Phase II of the study were obtained by two different methods. The first method was used for the initial two weeks of the study and consisted of a grab sample from each of the two sumps; one with recirculation and pH control (Fill 3) and the other recirculation, pH control, and raw sludge seed (Fill 4). The second sampling method employed during the remainder of Phase II consisted of obtaining a 24-hour composite sample using an Instrumentation Specialties Company Model 780 Automatic Sample Collector to remove 560 ml from each sump every hour. A 1.0-liter aliquot was taken from the 24-hour composite for analysis and the remaining leachate was returned to its respective sump with none being discarded.

In order to manually control the pH of both fills near neutral, sodium hydroxide was added to each collection sump at various intervals during the day. The sodium hydroxide was added by two slightly different methods. During the first nine weeks of the study, a predetermined amount of sodium hydroxide solution (approximately 150-200 ml) was added to the sumps, mixed, a 100-ml sample removed, the pH of the sample recorded, and the sample was titrated with 0.1N NaOH(sodium hydroxide)required to bring the sump volume (17 gallons) to neutral was calculated. This quantity was weighed, diluted to 150-200 ml. with distilled water, and set aside to cool. Six to 24 hours later the process was again repeated with the addition of the prepared sodium hydroxide solution.

After the ninth week the above procedure was changed and instead of placing the neutralizing solution in the sump prior to removing a sample for a pH reading and titration, a 100 ml sample was first removed, the pH recorded, and the sample was titrated with 0.1N or 0.5N NaOH solution.

Following the titration, the number of grams of sodium hydroxide required to raise the sump volume to neutral was calculated, weighed and placed in a flask of 150-200 ml of distilled water to cool. The solution in the flask was then added to the sump within a period of less than two hours. This change in technique was instigated since there was less need for semi-daily neutralizing additions after the ninth week as the pH drop became less drastic with time and there was the desire to know exactly how the pH had changed each day after nine weeks of neutralization. After the twelth week, a Beckman Model 940 Automatic pH Control provided immediate pH control whenever the pH was not within the optiman range (pH 6.8 to 7.4).

An apparatus for collecting gas was also used during Phase II of the study as described previously (Figure 3). In order to collect a sample of gas, a clean, two-stopcock gas sampler was attached to the sampling hose. Both stopcocks were opened for a period of approximately two minutes, then the one not attached to the hose was closed. This initial closure was followed by the closure of the stopcock attached to the hose, thus sealing a sample of gas inside the sampler. Samples of gas were taken after the 7th, 12th, 32nd, 44th and 58th weeks of the study. The gas sampler employed featured an opening covered with a rubber septum which allowed the removal of a gas aliquot with a syringe. Gas composition was then determined with a Fisher Gas Partitioner.

Refuse samples of both Fills 3 and 4 were taken at the end of the study period. Sampling consisted of reaching through the 3-inch ports constructed in the side of the two fills and removing approximately 700 grams of sample.

Analytical Methods

Analysis of Simulated Refuse

At the beginning of both Phase I and Phase II, a two-pound sample of the simulated refuse was collected and the organic fraction, consisting of paper, plastics, vegetable matter, meat, rags, and wood, was finely ground in a micromill and analyzed for carbon, hydrogen and nitrogen with a F and M Model 185 CHN Analyzer. Another portion of the finely ground sample was digested in concentrated sulfuric acid, neutralized, diluted with distilled water and analyzed for Kjeldahl nitrogen with a Technicon Auto-Analyzer; for potassium, sodium, calcium and magnesium with a Perkin-Elmer Atomic Absorption Spectrophotometer; and for phosphates using the procedure outlined in Standard Methods[13]. However, phosphate analysis in Phase II was performed using the Technicon Auto-Analyzer. In addition, the refuse removed from the simulated landfills during both the Phase I and Phase II Studies was analyzed for carbon, hydrogen, and nitrogen using the CHN analyzer, and moisture content and volatile solids in accordance with Standard Methods[13].

Analysis of Leachate and Sludge Samples

The fill leachate samples (Phase I and Phase II) were analyzed for 5-day biochemical oxygen demand (BOD_5), total organic carbon (TOC), chemical oxygen demand (COD), total suspended solids (TSS), volatile suspended solids (VSS), total solids (TS), alkalinity, acidity, total hardness, total and ammonia nitrogen, phosphate, calcium, magnesium, manganese, sodium, iron, chloride, pH and volatile acids. In addition, samples from the Phase II study were obtained to determine chromium, copper, zinc, lead, potassium and nickel. During the first 125 days of leachate production in the Phase I

study, nitrate determinations were also made using both specific ion electrodes and colorimetric methods. However, due to matrix interference difficulties with high concentrations of iron and chlorides, the results were unreliable. In order to avoid the problem experienced in Phase I, the Technicon Auto-Analyzer was used during Phase II to determine nitrate concentration. Sulfates were also determined during the first 125-day period of Phase I, but due to very low values, this analysis was subsequently deleted. Both nitrate and sulfate determinations were considered relatively unimportant in determining the effects of anaerobic stabilization. Sulfates were deleted completely from the Phase II study due to the interference of phosphate on the specific-ion electrode method used. Moreover, since it was the purpose of this research to determine the effect of leachate recirculation, pH control, and sludge seeding on landfill stabilization, the preceding analyses were considered adequate to reflect the process of stabilization in the fill and also demonstrate the possible accumulation of any pollutional substances.

Calcium, magnesium, manganese, sodium, iron, zinc, potassium, chromium, copper, lead, and nickel were measured with a Perkin-Elmer Atomic Absorption Spectrophotometer. Phosphates were determined by Hach Kit Methods for both Phase I and II, while the Auto-Analyzer was used to obtain total and ammonia nitrogen for both phases. Phosphates were also determined in Phase II by using the Auto-Analyzer as a comparison to the Hach Kit procedure. Chlorides were measured with an Orion Specific Ion Electrode using the known increment method. Because the concentrations of the hardness producing cations were determined, total hardness was found by the calculation method given in Standard Methods[13]. Volatile acids were measured on the F and M

Scientific 700 Chromatograph; pH was determined with a Leeds and Northrup pH meter; total organic carbon was measured with a Beckman Model 915 Total Organic Carbon Analyzer; and the remaining analyses were performed according to Standard Methods[13].

The previously described pipe-hose-beaker arrangement did collect some gas and it was analyzed using a Fisher Gas Partitioner. The production of gas was determined by the bubbles it produced when the hose was submerged below the water's surface. During gas production, samples were taken using an Orion double valved gas sampler.

CHAPTER III

PRESENTATION OF THE DATA

Results of the analyses performed on the simulated refuse and the leachate samples of Phase I are presented in this section together with similar data from Phase II which also included neutralization, gas analysis and sludge composition. The time scales used in this presentation (time since placement of refuse and since leachate production began) are related in that operating procedures allowed for the production of leachate 40 days after the placement in Phase I and seven days after the placement of refuse in Phase II.

Refuse Composition

Analysis of the organic portion of the refuse indicated an initial composition as shown in Table 4. The primary constituents of the refuse were carbon, hydrogen, and oxygen with nitrogen, potassium, sodium, phosphate, calcium and magnesium occurring in trace amounts.

Table 4

Initial Chemical Composition of the Organic Fraction of the Simulated Refuse of Phase I and II

Refuse Constituent	Weight, Percent	
	Phase I	Phase II
Carbon	47.20	49.50
Hydrogen	5.15	5.86
Oxygen	46.73	43.68
Nitrogen	0.65	0.25
Potassium	0.12	0.10
Sodium	0.12	0.59
Phosphate	0.03	0.00
Calcium	trace	trace
Magnesium	trace	trace
Total	100.00	100.00
Volatile Solids	98.62	98.32

The comparison of the initial composition of the organic fraction of the refuse (paper, plastic, vegetable matter, meat, rags and wood) with the composition of samples taken from the four simulated fills at the end of each study period is presented in Table 5.

Table 5

Comparison of the Initial Composition of the Organic Fraction of the Refuse with the Composition of Samples Taken from the Simulated Fills at the End of the Study Periods*

Refuse constituent	WEIGHT PERCENT					
	Phase I			Phase II		
	Initial	Fill 1	Fill 2	Initial	Fill 3***	Fill 4**
Carbon	47.20	46.00	37.00	49.50	41.40	44.40
Hydrogen	5.15	5.97	4.68	5.86	4.99	5.02
Oxygen	46.73	47.80	57.98	43.68	53.61	51.58
Nitrogen	0.65	---	---	0.25	---	---
Moisture	---	62.10	79.82	6.10	78.40	81.20
Volatile Solids	98.62	90.80	73.00	98.32	72.40	75.10

*Study period in Phase I was 720 days; 400 days in Phase II.

***Fill 3 refers to the fill with recirculation and pH control without raw sludge seeding.

**Fill 4 refers to the fill with recirculation, pH control and raw sludge seeding.

This table indicated that the refuse in all four fills had undergone reductions in organic carbon and volatile solids. The reductions, however, were much more dramatic in Fill 2 when compared to Fill 1, while in the seeded (Fill 4) and unseeded (Fill 3)fills, not much change could be noted over the period of observation.

Landfill Temperature

Temperature in the Phase I simulated landfill varied with daily ambient temperature fluctuations. The maximum (July) temperatures reached were 32°C in the control fill and 31°C in the recirculating fill; the minimum (December) temperatures were 5°C and respectively. The temperature variations in the control fill were slightly more dramatic than in the recirculating fill where temperature was moderated by the recycled leachate.

To determine whether insulation would provide control of large temperature fluctuation during extreme temperature periods, 3-inch fiberglass insulation was covered in 4-mm polyethylene plastic to exclude moisture. The insulation was installed after 238 days and the temperature fluctuations were greatly reduced (See Figure 4).

No temperature data were compiled during Phase II of the study due to the installation of insulation after 10 weeks of operation for Fill 3 and 7 weeks for Fill 4. In addition, the time of exposure of the fills without insulation is documented in Figure 4 for Phase I and was assumed to have been similar for Phase II. Moreover, the temperature during the months of May, June and July were not expected to be unfavorable to the anaerobic stabilization process.

Landfill Settlement

The cumulative surface settlement of both Phase I and Phase II fills is shown in Table 6. As previously mentioned, both fills experienced settlement due to the placement of cover soil and the initial addition of water to the fills. This initial settlement was not included in the settlement data of Phase I, and the cumulative settlement of both phases was calculated from the fill heights after the addition of cover soil and water.

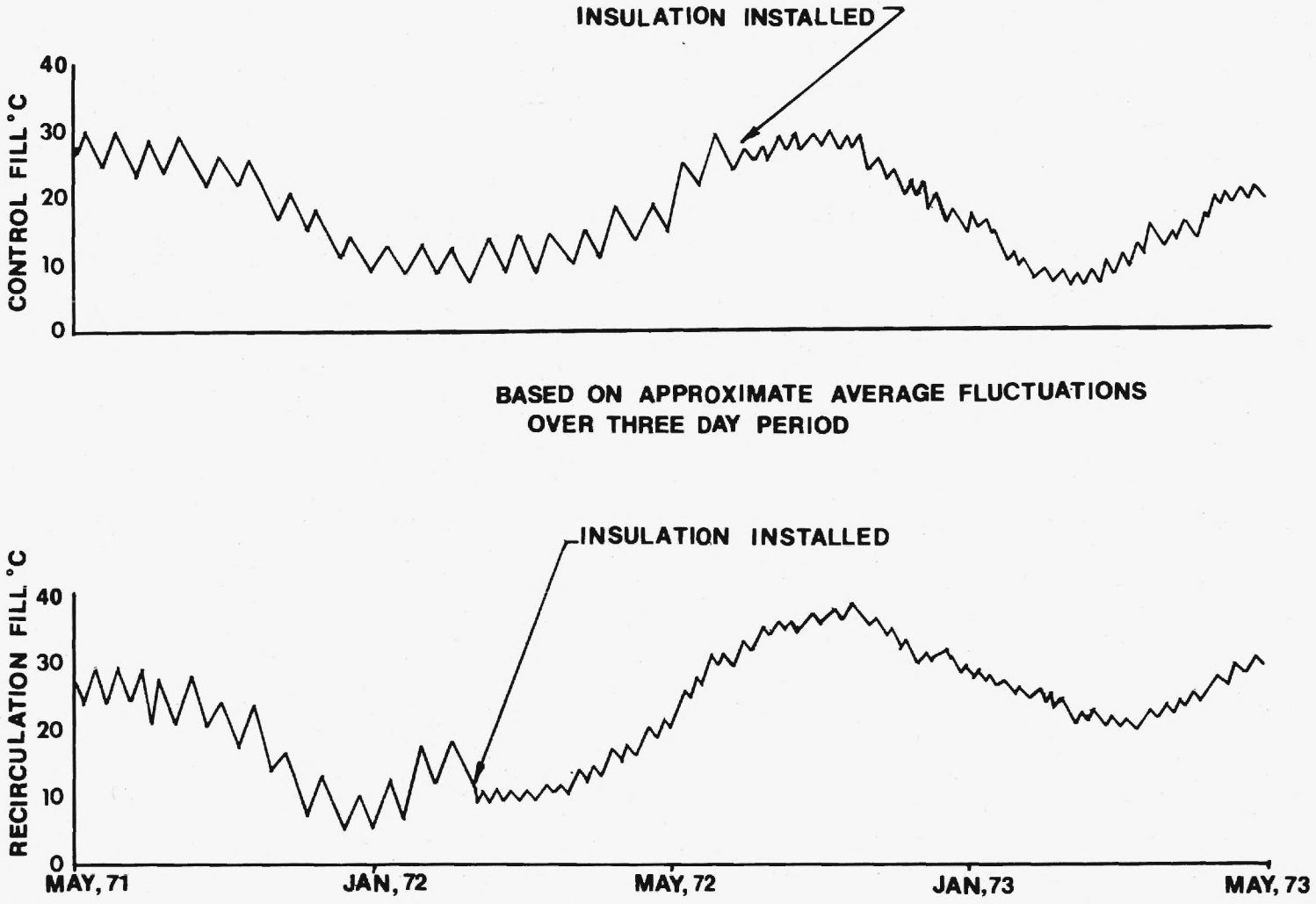

FIGURE 4: INTERNAL TEMPERATURE FLUCTUATIONS OF THE SIMULATED LANDFILL

Table 6

Cumulative Surface Settlement of the Simulated Landfills

Time Since Leachate Production, days	Cumulative Surface Settlement, feet			
	Fill 1*	Fill 2*	Fill 3*	Fill 4*
0	0	0	0	0
1	---	---	2.17	2.67
2	1.00	.50	---	---
3	---	---	2.17	2.96
6	1.21	0.79	---	---
8	---	---	2.62	3.17
10	1.21	0.79	---	---
11	---	---	2.83	3.33
13	1.21	0.79	---	---
14	---	---	3.04	3.62
17	1.22	0.78	---	---
20	1.28	0.78	---	---
22	---	---	3.13	3.75
24	---	0.88	---	---
27	1.44	0.88	---	---
31	1.48	0.95	---	---
38	1.48	0.95	---	---
50	1.48	0.98	---	---
52	---	---	3.42	3.92
65	---	---	3.50	4.00
72	---	---	3.50	4.00
81	1.50	0.99	3.63	4.25
94	1.50	1.01	3.68	---
117	1.50	1.02	---	---
140	1.50	1.03	3.74	---
160	1.50	1.03	3.81	---
180	1.51	1.04	3.88	4.31
210	1.51	1.05	3.88	---
260	1.51	1.06	---	---
280	1.51	1.07	---	---
310	1.51	1.07	3.88	4.31
340	---	---	3.91	4.31
400**	---	---	3.94	4.31
490	1.61	1.18	---	---
580	1.77	1.31	---	---
640	1.91	1.41	---	---
690	1.92	1.43	---	---
720***	1.94	1.47	---	---

*Fill 1 refers to control fill.
Fill 2 refers to recirculating fill.
Fill 3 refers to recirculating fill with pH control.
Fill 4 refers to recirculating fill with pH control and primary sludge seed.
**400 days, the end of Phase II study period.
***720 days, the end of Phase I study period.

The initial settlement of Phase II is included in Table 6 (Fills 3 and 4).

Leachate Analysis

Cumulative precipitation intercepted by both Phase I fills is shown in Table 7; that of Phase II is indicated in Table 8. The total precipitation intercepted by each fill was 190.35 inches including the water equivalent of 56.6 inches which was initially added to saturate the fills in Phase I, while in Phase II the total precipitation was 120.82 inches including 50.5 inches of water equivalent that was used to saturate the fills. Total leachate production from Fill 1 (See Table 9) was 18.154 inches (80 gallons) including the equivalent of 6.804 inches (30 gallons) which were produced when the fills were initially saturated. The amount added during neutralization and pH adjustment was also taken into account.

The concentrations of extracted materials in the leachate obtained from the simulated landfills of Phase I are tabulated in Tables 10 and 11, while those materials of Phase II are tabulated in Table 12. These concentrations are displayed graphically for all four fills in Figures 5 through 20.

Analyses for a few metals including chromium, copper, lead and nickel were performed the first five weeks and then every ten weeks but were found not to exist in the leachate from Phase II.

The initial leachate samples taken from the four fills were dark green in color and had a rotten garbage odor. The samples from the recirculating fills later lost this characteristic color and odor, whereas the control fill samples became light green in color and acquired a putrid odor similar to that of the short-chained organic acids. Upon exposure to air, however, the color of these control samples rapidly changed from green to dark brown as the ferrous iron was oxidized.

Table 7

Daily and Cumulative Precipitation
Received by Both Fills 1 and 2 of Phase I Since Refuse was Placed

Time Since Placement of Refuse, days	Precipitation, inches	Cumulative Precipitation, inches
0	0	0
5*	0.37	0.37
21	0.68	1.05
27	0.23	1.28
29	1.22	2.50
32	0.37	2.87
33**	56.60	59.47
36	0.98	60.45
38	0.18	60.64
40	3.07	63.71
45	1.11	64.82
46	0.98	65.80
47	1.72	67.52
61	1.02	74.54
66	3.70	78.24
70	1.23	79.47
77	1.90	81.37
90	3.50	84.87
124	0.74	85.61
134	0.86	86.47
136	1.84	88.31
165	1.85	90.16
169	4.06	94.22
180	1.23	95.45
194	1.84	97.29
197	3.69	101.98
204	6.15	108.13
205	3.69	111.82
207	2.09	113.91
224	3.12	117.03
227	1.61	118.64
231	1.24	119.88
237	1.12	121.00
241	0.36	121.36
255	0.72	122.08
267	2.81	124.89
270	1.12	126.01
288	1.82	127.83
307	2.54	130.37
317	0.74	131.11

Table 7 (continued)

Daily and Cumulative Precipitation
Received by Both Fills 1 and 2 of Phase I Since Refuse was Placed

Time Since Placement of Refuse, days	Precipitation, inches	Cumulative Precipitation, inches
320	0.99	132.10
328	3.92	136.02
335	0.19	136.21
337	0.12	136.33
338	0.37	136.70
351	0.12	136.82
354	0.62	137.44
365	4.80	142.24
366	0.12	142.36
373	0.62	142.98
378	0.23	143.21
381	0.38	143.59
394	0.84	144.43
400	0.71	145.15
404	1.13	146.27
406	0.24	146.51
433	0.24	146.75
444	0.40	147.15
459	1.33	148.48
468	1.00	149.48
482	0.34	149.92
493	0.54	150.36
498	2.20	152.56
508	1.20	153.76
514	0.93	154.69
520	0.54	155.23
526	1.36	156.59
531	0.25	156.84
536	0.36	157.20
539	0.14	157.34
542	0.21	157.55
543	0.20	157.75
546	0.68	158.43
553	2.84	161.27
561	1.31	162.58
565	0.24	162.82
570	2.20	164.82
583	2.10	166.92
589	0.78	167.70
601	0.24	167.94

Table 7 (continued)

Daily and Cumulative Precipitation
Received by Both Fills 1 and 2 of Phase I Since Refuse was Placed

Time Since Placement of Refuse, days	Precipitation, inches	Cumulative Precipitation, inches
606	0.35	168.29
623	1.85	170.14
627	0.04	170.18
631	0.44	170.72
633	1.12	171.74
639	2.14	173.88
649	4.16	178.04
655	0.10	178.14
659	2.60	180.74
673	1.60	182.30
683	0.77	183.98
697	2.29	186.27
707	2.95	189.22
715	0.24	189.46
724	0.89	190.35

*Fills were capped until 5 days after refuse was placed.

**250 gals. of water were added to each fill to bring them to field capacity.

Note: Rainfall was measured daily.

Table 8

Daily and Cumulative Precipitation
Received by Both Fills 3 and 4 of Phase II Since Refuse was Placed

Time Since Placement of Refuse, days	Precipitation, inches	Cumulative Precipitation, inches
0	0	0
1	2.26	2.26
5	23.75*	26.01
6	15.83**	41.84
7	8.66***	50.50
10	.98	51.48
12	8.66***	60.14
18	3.92	64.06
25	0.19	64.25
27	0.12	64.37
28	0.37	64.74
41	0.12	64.86
43	0.62	65.48
54	4.80	70.28
55	0.12	70.40
62	0.62	71.02
67	0.23	71.25
70	0.38	71.63
83	0.84	72.47
89	0.71	73.18
93	2.32****	75.50
95	0.24	75.74
122	0.24	75.98
133	0.40	76.38
148	1.33	77.71
157	1.00	78.71
171	0.34	79.05
182	0.54	79.59
189	2.20	81.79
197	1.20	82.99
203	0.93	83.92

*105 gallons of tap water added to each fill to bring them to field capacity.
**70 gallons of tap water added to each fill to bring them to field capacity.
***35 gallons of tap water added to each fill to bring them to field capacity.
****5 gallons of tap water added to each fill to speed recirculation, especially in Fill 4.

Table 8 (continued)

Daily and Cumulative Precipitation

Received by Both Fills 3 and 4 of Phase II Since Refuse was Placed

Time Since Placement of Refuse, days	Precipitation, inches	Cumulative Precipitation, inches
209	0.54	84.46
214	1.36	85.82
220	0.25	86.07
225	0.36	86.43
228	0.14	86.57
231	0.21	86.78
232	0.20	86.98
235	0.68	87.66
242	2.84	90.50
250	1.31	91.81
254	0.24	92.05
259	2.20	94.25
272	2.10	96.35
278	0.78	97.13
290	0.24	97.37
295	0.35	97.72
312	1.85	99.57
316	0.04	99.61
321	0.44	100.05
322	1.12	101.17
328	2.14	103.31
338	4.16	107.47
344	0.10	107.57
348	2.60	110.17
362	1.60	111.77
372	0.91	112.68
377	0.77	113.45
386	2.29	116.74
396	2.95	119.69
404	0.24	119.93
413	0.89	120.82

Table 9

Cumulative Leachate Production by the Control Landfill (Fill 1)*

Time Since Placement of Refuse, days	Leachate Production inches	Cumulative Leachate Production inches
0	0	0
33	6.804	6.804
47	2.040	8.844
67	0.034	8.878
65	0.454	9.332
72	0.566	9.898
81	0.198	10.096
116	0.294	10.390
125	0.180	10.570
153	0.239	10.809
178	0.216	11.025
189	0.210	11.235
197	0.181	11.416
228	0.121	11.537
249	0.204	11.741
284	0.192	11.933
312	0.378	12.311
326	0.179	12.490
331	0.191	12.681
336	0.203	12.884
337	0.036	12.920
339	0.090	13.010
346	0.191	13.201
371	0.203	13.404
385	0.197	13.601
389	0.209	13.810
397	0.179	13.989
425	0.090	14.079
460	1.090	15.160
490	1.212	16.372
500	0.481	16.853
506	0.300	17.153
520	0.754	17.907
535	0.454	18.361

Table 9 (continued)

Cumulative Leachate Production by the Control Landfill (Fill 1)*

Time Since Placement of Refuse, days	Leachate Production inches	Cumulative Leachate Production inches
545	1.125	19.486
553	0.520	20.006
562	0.941	20.947
577	0.840	21.787
598	0.525	22.312
615	0.815	23.127
626	0.561	23.688
631	0.824	24.512
641	1.621	26.133
651	1.121	27.254
665	0.510	27.764
680	0.520	28.284
689	0.910	29.194
699	0.810	30.004
716	0.312	30.316

*Total leachate production by Fill 1 was 80 gallons including the 30 gallons initially obtained by addition of water to reach field capacity. Leachate was measured either when enough had accumulated in Fill 1 to provide a proportional sample of 1.5 liters or two days after rainfall.

Table 10

Concentrations of Extracted Materials in Leachates Obtained from Control Landfill (Fill 1)

Time Since Leachate Production Began, days	0	14	24	32	39	48	81	116	125	153	173	189	197	228	249	284	312	332	347	398
COD, mg/l	4,320	9,150	10,380	10,260	12,000	11,700	9,200	10,100	11,700	12,200	12,300	14,400	15,600	18,100	15,600	13,300	13,800	---	11,100	9,000
BOD_5, mg/l	2,500	5,000	9,200	6,330	11,000	8,200	8,800	9,600	8,700	11,100	9,200	12,000	9,300	13,400	12,600	9,560	8,800	---	7,750	5,300
TOC, mg/l	1,230	1,910	2,622	2,622	2,802	2,835	2,864	2,259	2,418	2,680	2,696	3,049	3,409	5,000	3,590	3,000	2,930	3,180	3,005	2,430
TSS, mg/l	125	34	59	61	47	213	270	640	550	292	470	360	175	85	175	605	610	308	880	1,243
VSS, mg/l	45	20	47	52	37.6	93	160	332	314	182	268	210	104	76	141	283	286	146	432	602
TS, mg/l	2,442	5,819	6,323	8,300	8,736	6,789	5,530	7,250	7,358	7,620	7,875	8,320	8,130	12,500	8,780	7,716	7,167	6,965	6,260	5,602
Total Alkalinity, mg/l as $CaCO_3$	558	1,610	1,640	1,920	2,280	2,110	2,420	2,650	2,120	2,350	2,100	2,482	1,760	2,480	1,580	2,430	1,930	1,960	1,725	1,500
Total Acidity, mg/l as $CaCO_3$	690	1,100	1,350	1,400	1,780	2,170	1,836	1,390	2,090	2,230	2,780	2,865	3,260	3,460	2,610	2,000	2,400	3,360	3,460	1,950
pH	5.2	5.6	5.3	5.3	5.3	5.3	5.7	5.3	5.2	5.3	5.1	5.2	5.1	5.1	5.2	5.2	5.3	5.3	5.25	5.33
Total Hardness, mg/l as $CaCO_3$	450	1,400	1,850	1,810	1,940	1,754	1,410	1,429	1,694	2,232	2,354	2,306	2,449	5,555	3,463	2,424	2,299	1,622	1,326	1,576
Acetic Acid, mg/l	500	2,111	2,360	2,664	3,666	3,268	2,789	3,285	2,590	3,280	3,440	3,393	3,550	5,160	3,754	3,460	2,830	2,275	2,210	1,000
Propionic Acid, mg/l	369	1,595	1,834	2,038	2,313	2,108	1,875	2,625	2,110	2,290	2,190	2,400	2,214	2,840	1,742	1,640	1,580	1,380	1,330	720
Butyric Acid, mg/l	110	965	1,075	1,050	1,280	1,164	1,000	1,203	1,424	1,195	1,215	1,350	1,750	1,830	1,770	1,800	1,740	1,540	1,460	970
Valeric Acid, mg/l	Nil	425	575	625	535	612	643	893	656	708	652	730	801	1,000	705	750	768	590	560	855
Phosphate, mg/l $PO_4^{\equiv}$	26	3.0	5.0	7.8	2.8	2.9	3.3	4.2	3.4	2.8	1.7	1.6	1.5	1.3	1.5	0.9	1.1	.6	.40	.5
Organic Nitrogen, mg/l as N	56	47	61.4	62	75	48	40	177	64	6	20	12	43	107	116	76	63	28	40	124
Ammonia Nitrogen, mg/l as N	56	150	167.6	187	185	192	148	103	130	260	214	218	264	117	52	110	103	152	132	88
Nitrate Nitrogen, mg/l NO_3^-	13.3	32	89	84	115	15.0	---	9.5	12	---	---	---	---	---	---	---	---	---	---	6.4
Chloride, mg/l	322	385	109.8	105.1	97.9	340	---	170	240	210	208	312	308	180	300	280	295	124	137	143
Sulfate, mg/l $SO_4^{=}$	84	126	108	81	156	17	2	7	1	16	---	---	---	---	---	---	---	---	---	---
Calcium, mg/l Ca	125	430	470	590	750	545	430	375	420	600	578	565	545	1,250	850	550	490	433	385	350
Magnesium, mg/l Mg	26	71.8	67	75	68	64	52	49	53	80	85	85	75	260	210	90	65	40	53	39
Manganese, mg/l Mn	3	10	5	6.2	8.8	8.5	10	7.5	10	16	14	15	16	18	19	12	12	19	11	10
Sodium, mg/l Na	63.8	125	132	132	143	150	180	118	135	155	154	155	148	160	140	85	140	103	110	130
Iron, mg/l Fe	9	21	70	30	95	65	60	155	230	200	300	290	420	185	250	370	440	190	70	292
Total Volatile Acids, mg/l as Acetic Acid	865	4,310	4,925	5,399	6,721	6,133	5,370	6,750	5,655	6,370	6,420	6,693	7,000	9,300	6,785	6,460	5,745	4,795	4,615	2,745

Table 10 (continued)

Concentrations of Extracted Materials in Leachates Obtained from Control Landfill (Fill 1)

Time Since Leachate Production Began, days	428	473	506	530	556	606	636	672	704
COD, mg/l	9,500	8,950	8,050	7,845	6,210	6,120	6,140	5,750	4,990
BOD_5, mg/l	6,500	6,050	6,600	4,800	3,835	4,300	4,200	4,300	3,350
TOC, mg/l	2,910	2,910	2,665	2,127	2,410	1,400	2,090	2,190	1,990
TSS, mg/l	800	680	800	540	1,170	1,010	510	750	750
VSS, mg/l	400	470	310	340	380	300	210	305	310
TS, mg/l	5,800	3,750	3,650	2,425	2,400	2,100	2,050	2,100	2,100
Total Alkalinity, mg/l as $CaCO_3$	1,750	2,040	2,040	1,970	2,040	2,040	1,800	2,040	2,240
Total Acidity, mg/l as $CaCO_3$	2,100	1,710	1,440	1,840	1,670	1,670	2,350	1,740	1,640
pH	5.60	5.68	5.90	5.95	6.10	6.00	6.10	6.20	6.30
Total Hardness, mg/l as $CaCO_3$	1,840	1,580	1,310	1,190	1,170	1,160	1,840	790	750
Acetic Acid, mg/l	2,410	2,520	2,220	2,750	2,920	2,910	1,750	1,750	1,550
Propionic Acid, mg/l	1,100	1,520	1,260	720	400	410	1,200	1,100	1,150
Butyric Acid, mg/l	940	500	704	714	90	40	410	400	400
Valeric Acid, mg/l	710	395	428	420	70	30	395	395	200
Phosphate, mg/l $PO_4^{=}$	0.51	0.51	0.27	0.29	0.23	0.32	0.28	0.27	0.26
Organic Nitrogen, mg/l as N	48	46	42	85	87	85	59	16	26
Ammonia Nitrogen, mg/l as N	88	86	80	35	28	19	8	8	12
Nitrate Nitrogen, mg/l NO_3^-	.09	.07	.07	.07	.06	.17	.04	.04	.15
Chloride, mg/l	150	130	164	164	200	134	134	85	110
Sulfate, mg/l $SO_4^{=}$	---	---	---	---	---	---	---	---	---
Calcium, mg/l Ca	400	350	230	200	175	155	140	110	142
Magnesium, mg/l Mg	45	45	12	22	22	20	20	11	12
Manganese, mg/l Mn	15	6.5	7.5	3.5	4.5	4.5	3.5	4.5	2.5
Sodium, mg/l Na	130	145	130	140	170	275	235	235	210
Iron, mg/l Fe	240	280	295	280	270	270	250	245	240
Zinc, mg/l Zn	---	---	---	---	42.5	41	10	12	9
Total Volatile Acids, mg/l as Acetic Acid	3,950	4,570	3,915	3,420	3,300	3,820	3,670	3,240	3,090

Table 11

Concentrations of Extracted Materials in Leachates Obtained from Recirculating Landfill (Fill 2)

Time Since Leachate Production Began, days	0	10	18	24	31	39	48	58	67	96	111	126	140	161	189	197	219	228	249	284	284	312	332	366	398
COD, mg/l	4,280	9,288	8,870	9,080	8,111	7,700	8,140	9,580	10,400	10,025	10,500	10,500	10,350	8,890	5,810	4,270	3,550	2,970	2,840	2,580	1,950	1,280	1,050	1,110	800
BOD_5, mg/l	2,750	5,200	6,900	6,800	4,300	5,400	6,202	6,400	6,380	7,200	8,700	8,500	10,100	9,405	6,650	3,500	2,860	1,400	2,500	2,420	760	760	540	700	510
TOC, mg/l	2,130	1,120	2,260	2,040	2,394	1,818	2,665	2,000	2,675	2,798	1,990	1,979	1,952	1,542	1,280	1,067	914	710	565	500	308	256	480	475	545
TSS, mg/l	93	13.6	12	36.5	70.5	25	37.0	120	301	143	222	258	385	187	232	220	131	122	145	124	67	305	358	370	405
VSS, mg/l	22.5	---	9	27.5	45	18.8	16.9	70	161	78	158	142	188	118	156	116	76	74	87	56	37	18	41	69	72
TS, mg/l	2,349	4,329	4,552	5,023	5,400	4,728	4,941	5,250	5,440	5,980	5,830	6,918	6,106	5,336	4,090	3,987	3,240	2,792	2,370	2,510	1,848	1,627	1,784	2,038	---
Total Alkalinity, mg/l as $CaCO_3$	302	700	865	1,080	1,200	1,370	1,525	1,438	1,035	1,900	2,350	1,640	1,670	1,640	1,550	1,342	1,115	952	980	925	738	692	800	780	800
Total Acidity, mg/l as $CaCO_3$	554	1,900	1,540	1,350	1,000	1,390	1,265	1,530	1,765	1,798	1,730	1,830	1,700	1,630	500	333	240	180	166	133	84	80	152	200	250
pH	5.05	4.8	5.0	5.1	5.3	5.4	5.3	5.3	5.1	5.4	5.5	5.3	5.3	5.2	6.3	6.6	6.8	6.9	7.0	7.1	7.4	7.3	7.1	6.91	6.90
Total Hardness, mg/l as $CaCO_3$	370	895	880	1,010	890	1,040	1,222	1,483	1,532	1,701	1,987	1,495	2,296	1,948	1,469	1,146	978	677	539	661	513	377	146	520	---
Acetic Acid, mg/l	1,638	556	2,000	1,843	1,475	1,583	1,795	2,146	2,438	2,742	2,438	2,470	2,380	1,877	2,925	608	734	770	670	111	234	365	400	525	1,050
Propionic Acid, mg/l	960	394	1,242	1,467	1,554	1,594	1,580	1,752	1,953	2,203	1,953	1,865	2,020	1,472	1,995	714	195	111	104	57	223	110	160	120	55
Butyric Acid, mg/l	1,300	235	1,235	1,163	1,375	1,250	1,200	1,198	1,094	1,156	1,047	1,124	937	735	665	286	194	68	65	Nil	62	44	20	26	95
Valeric Acid, mg/l	500	735	50	833	688	670	714	800	858	857	786	842	625	556	585	276	87	65	50	Nil	35	Nil	13	33	180
Phosphate, mg/l $PO_4^{\equiv}$	22	1.5	2.1	0.65	0.81	0.67	0.82	0.85	0.98	0.65	0.38	0.50	0.39	0.82	0.47	0.26	0.24	0.07	0.08	0.09	0.12	0.09	.03	.15	.09
Organic Nitrogen, mg/l as N	20	0	30	405	37.5	39.5	41	30	39	62	92	28	7	3	4	Nil	Nil	1	3	2	1	7	nil	16	---
Ammonia Nitrogen, mg/l as N	70	68	113.5	86.5	77.5	76.5	64	69	81	84	80	71	135	126	80	62	56	39	31	35	27	13	30	26	---
Nitrate Nitrogen, mg/l NO_3^-	6.2	71.4	56.6	76.6	48	49	11.0	11.5	12.0	16.0	21.0	14.0	---	---	---	---	---	---	---	---	---	---	---	---	---
Chloride, mg/l	210	210	248	94.5	91	115	220	164	176	140	188	170	210	236	300	270	260	248	224	220	218	202	119	116	---
Sulfate, mg/l $SO_4^{=}$	102	138	81	51	30	12	11	Nil	12	2	1	3	---	---	---	---	---	---	---	---	---	---	---	---	---
Calcium, mg/l Ca	60	315	350	435	420	430	420	415	440	500	550	385	600	475	400	340	290	190	145	175	135	82	115	136	---
Magnesium, mg/l Mg	16.5	59	53.5	62.5	56	56	50	50	53	55	62	44	70	60	50	45	40	40	38	40	35	38	32	34	---
Manganese, mg/l Mn	4	30	50	65	62	62	75	75	80	80	85	60	93	80	59	50	44	19	10	19	14	8	3	8	---
Sodium, mg/l Na	61.5	109	81.4	91.4	85	84	95	85	88	90	98	70	84	75	61	59	50	60	55	60	55	75	52	63	---
Iron, mg/l Fe	4.4	19.5	19	80	43	110	25	35	40	45	110	150	150	210	90	13	5	1.4	1.9	14	4	1.2	5	14	---
Total Volatile Acids, mg/l as Acetic Acid	3,605	1,465	3,875	4,370	4,080	4,120	4,315	4,855	5,270	5,815	5,195	5,245	5,025	3,895	5,340	1,545	1,075	945	830	155	475	485	555	660	1,265

Table 11 (continued)

Concentrations of Extracted Materials in Leachates Obtained from Recirculating Landfill (Fill 2)

Time Since Leachate Production Began, days	428	473	506	530	556	606	636	672	704
COD, mg/l	870	490	225	258	192	113	56	84	70
BOD_5, mg/l	440	264	120	85	75	46	44	45	44
TOC, mg/l	510	515	375	325	310	325	520	345	250
TSS, mg/l	350	310	250	140	140	510	400	310	200
VSS, mg/l	50	100	90	110	80	280	250	110	70
TS, mg/l	2,100	2,800	2,000	820	720	950	900	850	700
Total Alkalinity, mg/l as $CaCO_3$	800	840	840	780	760	620	840	880	840
Total Acidity, mg/l as $CaCO_3$	250	250	250	230	240	260	110	180	140
pH	6.90	6.82	7.10	6.95	7.05	6.45	7.0	7.10	7.0
Total Hardness, mg/l as $CaCO_3$	375	250	200	200	170	110	100	90	105
Acetic Acid, mg/l	1,110	1,000	875	940	865	740	410	140	75
Propionic Acid, mg/l	70	90	40	38	42	75	75	35	35
Butyric Acid, mg/l	110	120	20	40	40	75	120	30	0
Valeric Acid, mg/l	170	145	50	70	60	85	20	10	0
Phosphate, mg/l $PO_4^{\equiv}$	.08	.08	.05	.06	.05	.06	.10	.05	.07
Organic Nitrogen, mg/l as N	3	4	6.5	14	7	0	0	0	0
Ammonia Nitrogen, mg/l as N	18	15	3.5	0	0	0	0	0	0
Nitrate Nitrogen, mg/l NO_3^-	.09	.04	.08	.06	.04	.05	.05	.05	.05
Chloride, mg/l	158	204	236	176	150	110	76	70	70
Sulfate, mg/l $SO_4^{=}$	---	---	---	---	---	---	---	---	---
Calcium, mg/l Ca	40	25	27	27	11	11	9	9	9
Magnesium, mg/l Mg	30	14	13	12	11	11	10	11	10
Manganese, mg/l Mn	8	10	0	0	.4	.1	.2	0	0
Sodium, mg/l Na	60	70	40	60	100	120	120	120	120
Iron, mg/l Fe	0	0	0	0	0	0	0	0	0
Total Volatile Acids, mg/l as Acetic Acid	1,342	1,240	955	1,039	961	902	536	194	103

Table 12

Concentration of Extracted Materials in Leachate Obtained from Fill 3 and 4, Phase II

Time Since Leachate Production Began		Days 2	8	17	24	31	38	45	52	58	68	73	80	87
		Date 5/3	5/9	5/18	5/25	6/1	6/8	6/15	6/22	6/28	7/8	7/13	7/20	7/27
COD, mg/l	*A	460	5,200	7,200	9250	11,750	11,200	11,000	15,000	15,400	17,400	18,000	15,800	17,600
	**B	5,850	6,900	7,600	9050	9,200	9,700	9,400	8,700	7,200	7,950	8,200	7,875	7,075
BOD_5, mg/l	A	195	3,350	5,600	7,900	9,200	8,500	8,000	7,600	10,300	12,100	11,200	12,300	14,650
	B	4,150	3,900	4,400	6,600	7,150	6,800	6,800	5,200	5,400	5,900	5,600	4,600	5,300
TOC, mg/l	A	332	2,030	2,720	2,860	3,655	3,820	3,440	4,000	4,430	4,330	4,800	4,500	4,925
	B	1,975	2,360	2,340	2,610	2,375	2,660	2,485	2,310	2,370	2,400	2,060	2,055	1,900
TSS, mg/l	A	---	146	210	355	441	558	364	814	768	1,225	1,101	690	463
	B	---	126	253	281	401	374	569	880	---	978	926	747	1,060
VSS, mg/l	A	---	100	72	111	146	205	85	270	280	393	342	192	151
	B	---	78	144	142	171	161	250	140	---	226	244	175	251
TS, mg/l	A	---	3,154	4,983	8,097	9,699	10,478	11,860	11,006	11,346	12,169	12,314	13,458	12,770
	B	---	3,896	4,745	5,206	6,219	6,811	7,756	5,678	6,012	6,135	6,534	6,912	6,387
Total mg/l $CaCO_3$ Alkalinity	A	93	964	1,735	3,240	3,290	3,565	3,765	3,400	4,320	4,560	4,700	4,540	4,900
	B	1,500	1,870	2530	2,830	2,710	2,660	3,220	2,740	2,940	2,780	2,540	4,360	3,150
Total mg/l $CaCO_3$ Acidity	A	30	920	2010	690	520	590	420	1,020	1,370	860	900	580	800
	B	325	485	830	860	930	630	835	550	640	500	560	550	400
pH	A	6.78	5.45	5.35	6.58	6.58	6.05	6.10	5.89	5.88	6.24	6.19	6.59	6.32
	B	6.61	6.52	6.28	6.50	6.32	6.34	6.30	6.81	6.69	6.61	6.55	6.88	7.00
Hardness mg/l as $CaCO_3$	A	---	563	872	989	1,206	1,249	1,293	1,639	1,168	1,335	1,428	1,455	1,167
	B	---	537	790	863	997	1,043	1,405	1,055	642	847	898	1,057	492
Acetic Acid, mg/l	A	44	1,000	1,875	2,150	2,300	2,910	2,950	3,140	3,950	4,000	2,400	2,530	2,200
	B	950	1,575	1,810	1,825	2,250	2,350	2,065	380	272	220	1,230	900	1,410
Propionic Acid, mg/l	A	14	1,020	1,800	2,025	2,160	2,550	2,650	2,750	3,380	3,750	2,270	2,210	2,320
	B	440	1,140	1,460	1,235	1,275	1,360	2,600	2,260	2,620	3,580	2,970	2,430	2,650
Butyric Acid, mg/l	A	13	350	800	850	1,075	1,275	1,425	1,500	1,770	2,000	1,495	1,475	1,350
	B	175	800	765	738	825	1,000	1,040	665	145	320	95	nil	50
Valeric Acid, mg/l	A	13	88	295	375	475	610	725	855	1,220	1,970	1,790	1,820	1,670
	B	0	25	130	200	225	300	395	385	260	440	nil	100	100
Phosphate, mg/l PO_4	A	0.27	--	1.47	0.27	0.50	0.45	0.25	0.34	0.31	0.22	---	0.20	0.28
	B	3.90	--	0.22	0.10	0.26	1.20	1.50	0.25	0.29	0.29	---	0.18	0.27
Organic Nitrogen mg/l as N	A	---	92	45	4	30	26	92	67	114	67	75	83	75
	B	---	107	119	119	126	130	66	42	32	47	55	50	46
Ammonia Nitrogen mg/l as N	A	---	172	270	318	320	324	335	339	376	400	400	400	400
	B	---	325	413	427	392	437	396	343	304	268	260	244	176
Nitrate Nitrogen mg/l as NO_3^-	A	---	---	3.1	2.7	4.0	3.3	2.2	3.1	3.3	2.7	3.1	0.4	0.6
	B	---	5.3	4.4	3.5	4.0	4.2	3.5	1.1	1.9	2.0	1.6	0.6	0.5
Chloride, mg/l Cl^-	A	---	---	186	243	257	---	286	250	238	272	276	286	268
	B	---	191	254	252	253	316	305	293	287	290	331	324	307
Calcium, mg/l Ca	A	---	153	246	290	335	366	382	440	305	325	340	365	300
	B	---	136	205	230	270	275	390	285	165	220	225	230	80
Magnesium mg/l Mg	A	---	17	31	34	41	43	43	47	49	52	53	52	53
	B	---	31	38	40	44	46	55	50	53	63	67	67	36
Manganese mg/l Mn	A	---	19	19	19	19	19	10	19	13	12	13	12	11
	B	---	10	19	19	19	19	15	19	6	8	14	14	23
Sodium, mg/l Na	A	---	118	294	1,210	1,410	1,880	1,600	1,100	1,590	1,400	1,600	1,600	2,300
	B	---	182	248	336	630	600	750	613	625	1,050	800	825	400
Iron, mg/l Fe	A	---	42	53	50	91	68	80	174	100	160	188	115	100
	B	---	29	48	49	59	73	99	56	nil	13	18	100	57
Potassium, mg/l K	A	---	---	---	535	595	710	550	530	570	600	590	605	563
	B	---	---	---	690	740	---	500	392	345	360	385	400	231
Zinc, mg/l Zn	A	---	---	---	1.3	1.0	1.3	5.0	4.3	7.5	20	22	12	17
	B	---	---	---	0.8	0.8	---	0.6	1.3	0.8	0.8	1.3	1.0	0.6
Total Volatile Acid mg/l as Acetic Acid	A	72	2,120	4,055	5,570	5,060	6,200	6,490	6,880	8,620	9,560	6,310	6,390	5,980
	B	1,425	3,060	3,587	3,450	3,975	4,305	5,105	2,890	2,645	3,600	3,695	2,930	3,575

** Fill 3
* Fill 4

Table 12 (continued)

Concentration of Extracted Materials in Leachate Obtained from Fill 3 and 4, Phase II

Time Since Leachate Production Began		Days 114 Date 8/23	134 9/12	156 10/4	169 10/17	183 10/31	206 11/23	221 12/8	234 12/21	255 1/11	282 2/7	325 3/22	350 4/16	365 5/1	394 5/30
COD, mg/l	*A	17,710	16,650	16,510	14,000	13,200	14,500	13,000	11,800	7,100	5,500	2,480	1,450	950	780
	**B	1,860	950	850	840	745	560	560	490	403	376	350	340	290	270
BOD_5, mg/l	A	14,500	14,000	13,000	12,300	11,500	12,300	12,500	9,450	5,500	5,050	2,300	1,100	660	250
	B	1,400	860	500	367	232	220	130	125	44	62	66	85	90	88
TOC, mg/l	A	5,700	5,655	5,685	5,080	5,210	4,940	4,220	3,660	3,300	2,600	1,140	930	980	980
	B	1,650	815	745	660	610	540	610	570	275	250	347	325	450	470
TSS, mg/l	A	750	780	750	820	840	1,180	720	760	1,030	720	900	850	800	650
	B	470	490	480	510	610	420	350	330	280	310	260	310	340	410
VSS, mg/l	A	110	60	70	100	70	85	65	70	450	60	250	250	170	140
	B	140	140	130	120	130	160	110	90	120	140	150	120	120	120
TS, mg/l	A	12,000	10,500	8,500	8,500	7,800	7,000	6,440	5,610	4,380	3,440	2,435	2,710	2,210	1,460
	B	5,400	3,800	4,200	3,400	3,000	2,560	2,480	2,140	1,460	1,170	1,200	1,100	1,150	1,150
Total mg/l $CaCO_3$ Alkalinity	A	4,450	4,400	4,560	4,280	4,840	4,870	4,880	5,400	5,800	6,010	6,180	5,840	5,760	5,420
	B	2,960	2,680	2,660	2,620	2,580	2,480	2,400	2,510	2,560	2,510	3,740	2,920	2,760	2,840
Total mg/l $CaCO_3$ Acidity	A	890	1,010	1,090	1,070	1,240	1,340	1,390	1,310	800	810	310	260	240	240
	B	410	400	400	360	310	300	230	210	205	160	140	160	150	170
pH	A	6.45	6.60	6.70	6.65	6.65	6.75	7.40	7.40	7.45	7.50	7.40	7.20	7.20	7.10
	B	7.10	7.20	7.45	7.30	7.20	7.25	7.15	7.30	7.05	7.15	7.10	7.03	7.03	7.00
Hardness mg/l as $CaCO_3$	A	750	540	260	210	200	190	180	180	160	160	140	140	140	140
	B	240	210	205	180	180	170	160	160	140	140	120	110	110	110
Acetic Acid, mg/l	A	2,260	2,310	2,420	2,100	2,200	2,140	1,700	2,000	1,800	1,600	1,400	540	280	90
	B	1,160	1,120	1,000	640	310	210	110	120	100	85	80	78	100	75
Propionic Acid mg/l	A	5,780	5,350	5,100	3,620	2,420	1,540	890	680	540	540	640	110	75	40
	B	2,000	350	250	42	15	15	25	30	20	60	60	40	40	40
Butyric Acid, mg/l	A	1,000	720	600	510	370	310	215	210	110	80	25	10	5	1
	B	50	50	40	25	12	0	0	5	20	0	10	0	2	0
Valeric Acid, mg/l	A	1,420	1,300	1,200	640	540	400	210	200	80	0	5	0	0	0
	B	120	90	75	50	10	10	0	0	0	0	0	0	0	0
Phosphate, mg/l $PO_4^{\equiv}$	A	0.17	0.30	0.21	0.23	0.17	0.12	0.12	0.12	0.17	0.14	0.28	0.31	0.28	0.24
	B	0.42	0.37	0.22	0.30	0.31	0.24	0.23	0.37	0.21	0.17	0.06	0.09	0.11	0.14
Organic Nitrogen mg/l as N	A	48	48	32	96	254	157	133	131	70	30	26	16	50	44
	B	54	43	25	58	30	132	105	91	5	5	7	15	15	35
Ammonia Nitrogen mg/l as N	A	448	408	376	360	210	98	67	67	126	104	101	76	62	16
	B	216	224	192	176	197	154	105	56	49	3	1	25	40	65
Nitrate Nitrogen mg/l as NO_3^-	A	0.20	0.18	0.15	0.24	0.25	0.20	0.19	0.19	0.23	0.05	0.05	0.15	0.11	0.11
	B	0.23	0.17	0.17	0.15	0.17	0.13	0.12	0.13	0.14	64	64	9.6	12	12
Chloride, mg/l Cl^-	A	280	250	310	320	290	300	310	320	340	170	160	130	130	130
	B	330	300	380	380	350	350	340	360	340	240	180	130	110	130
Calcium, mg/l Ca	A	310	350	280	155	125	70	20	15	14	7	12	12	15	15
	B	80	2.3	2.4	2.6	5.5	5.5	11	12	12	9	8	13	12	12
Magnesium mg/l Mg	A	55	24	12	12	31	31	34	34	36	36	20	18	15	15
	B	45	40	25.5	16	22	9	15	14	15	14	14	15	12	12
Manganese mg/l Mn	A	13	11	4.5	3.1	2.7	0.4	0	0	0	0	0	0	0	0
	B	17	21	25	6.5	6.8	7.5	7.5	3.5	3.5	4.5	4.5	4.0	2.5	2.5
Sodium, mg/l Na	A	1,600	1,400	1,200	1,250	1,150	1,125	1,200	1,200	1,250	1,350	1,000	890	840	840
	B	560	520	500	490	470	470	480	490	500	470	490	500	290	290
Iron, mg/l Fe	A	110	120	150	110	75	75	40	20	21	18	15	15	22	22
	B	25	12	8	8	3	3	5	5	7	7	12	12	8	8
Potassium, mg/l K	A	550	550	510	515	500	495	480	310	310	310	300	300	300	300
	B	235	340	340	340	340	350	350	310	310	340	340	340	340	340
Zinc, mg/l Zn	A	17	15	10	0.95	0.05	0	0	0	0	0	0	0	0	0
	B	1.0	0	0.02	0	0	0	0	0	0	0	0	0	0	0
Total Volatile Acid, mg/l as Acetic Acid	A	8,480	7,920	7,686	5,760	4,740	3,600	2,690	2,415	2,360	2,035	1,940	640	350	125
	B	2,885	1,495	1,370	720	336	222	130	147	130	100	135	110	130	100

** Fill 3
* Fill 4

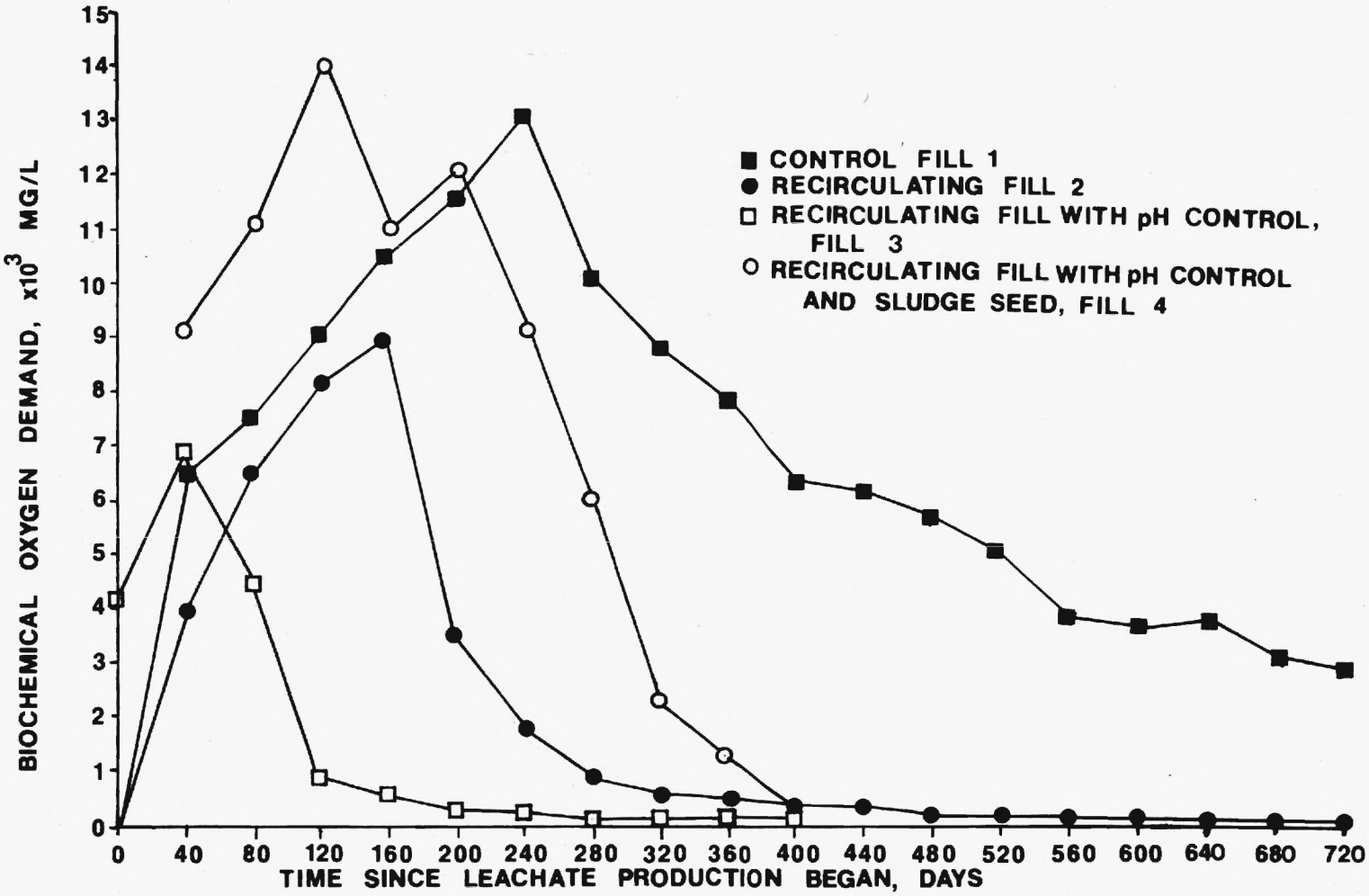

FIGURE 5: BIOCHEMICAL OXYGEN DEMAND OF LEACHATE

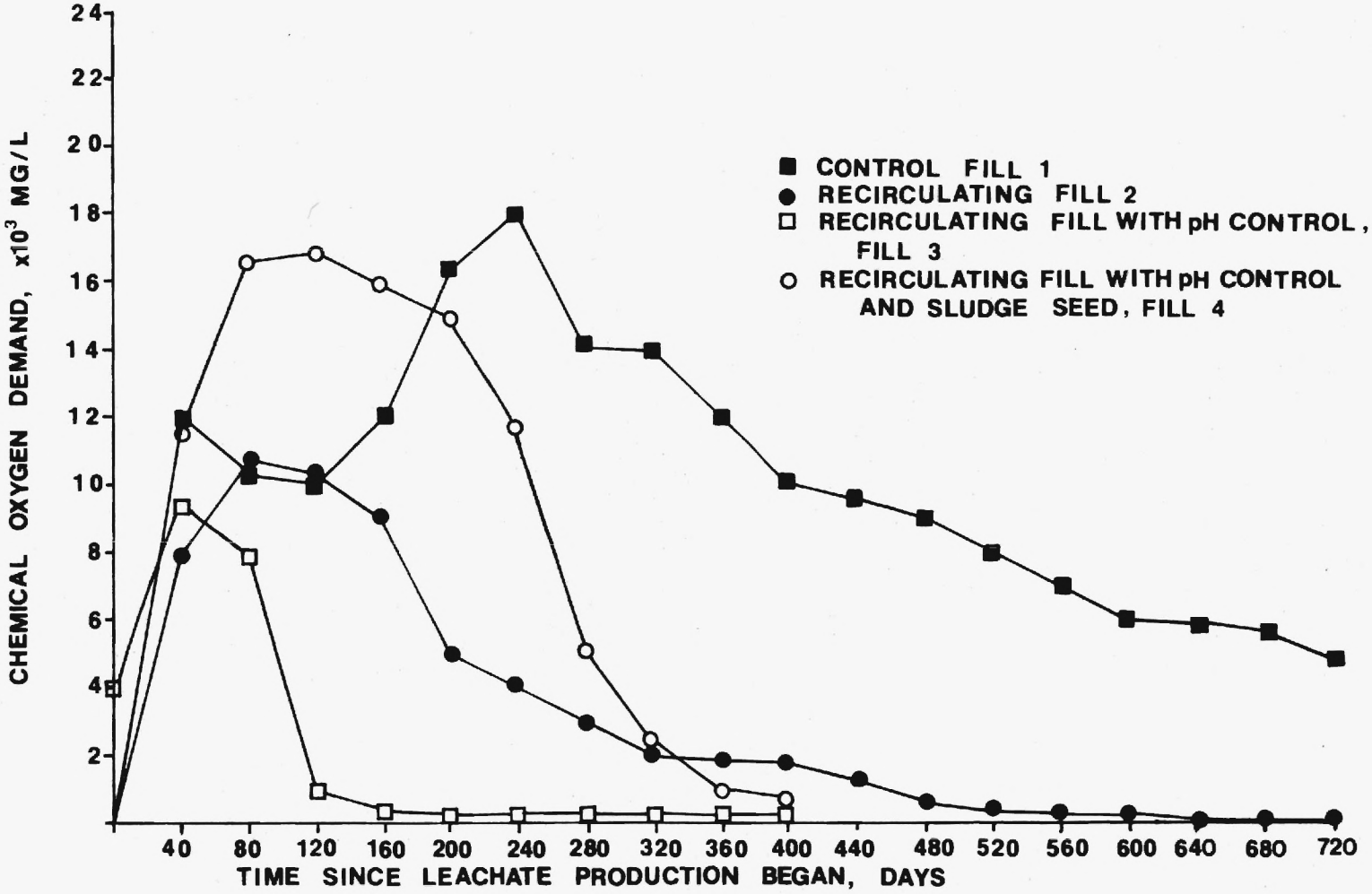

FIGURE 6: CHEMICAL OXYGEN DEMAND OF LEACHATE

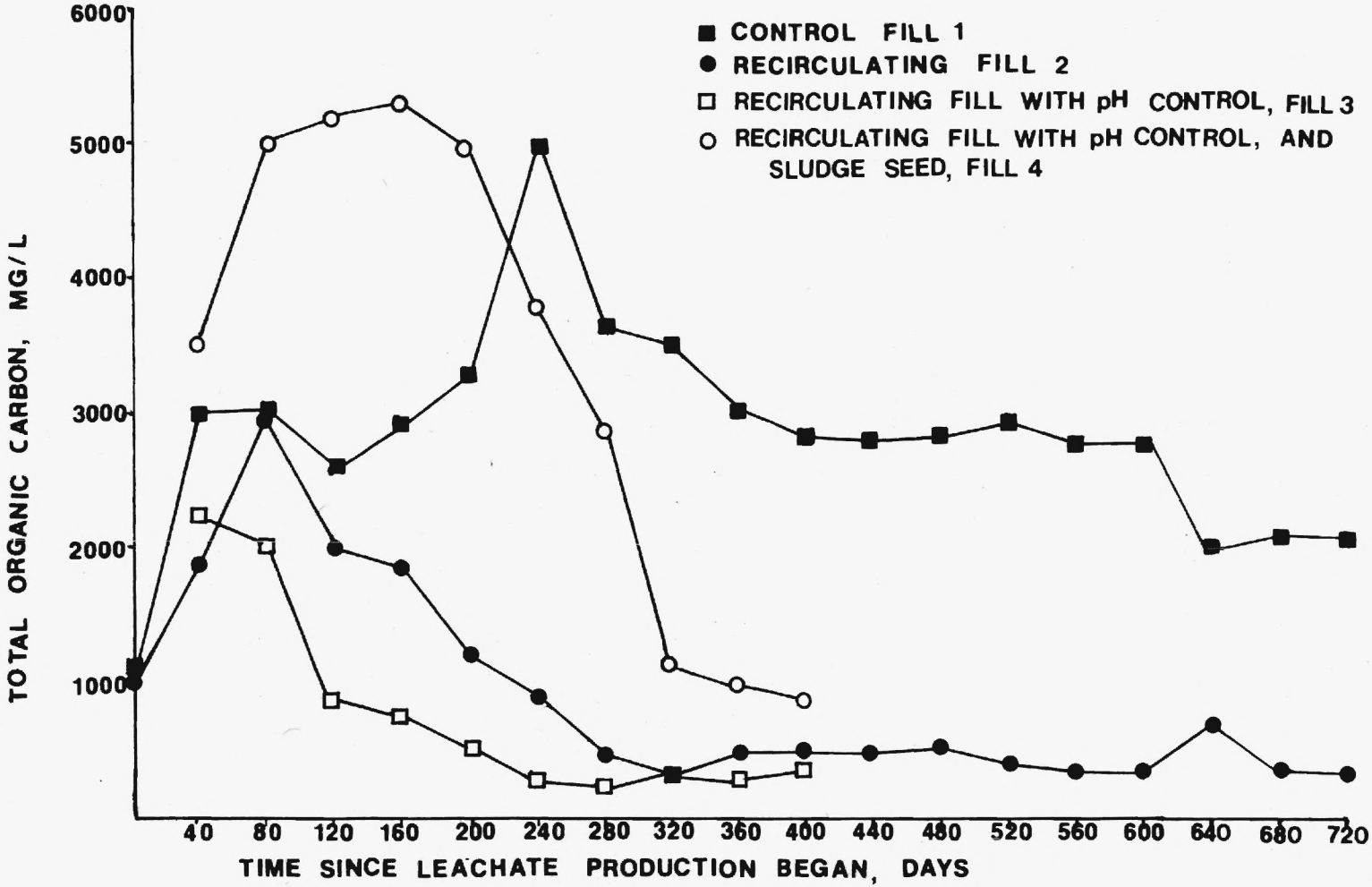

FIGURE 7: TOTAL ORGANIC CARBON CONCENTRATION OF LEACHATE

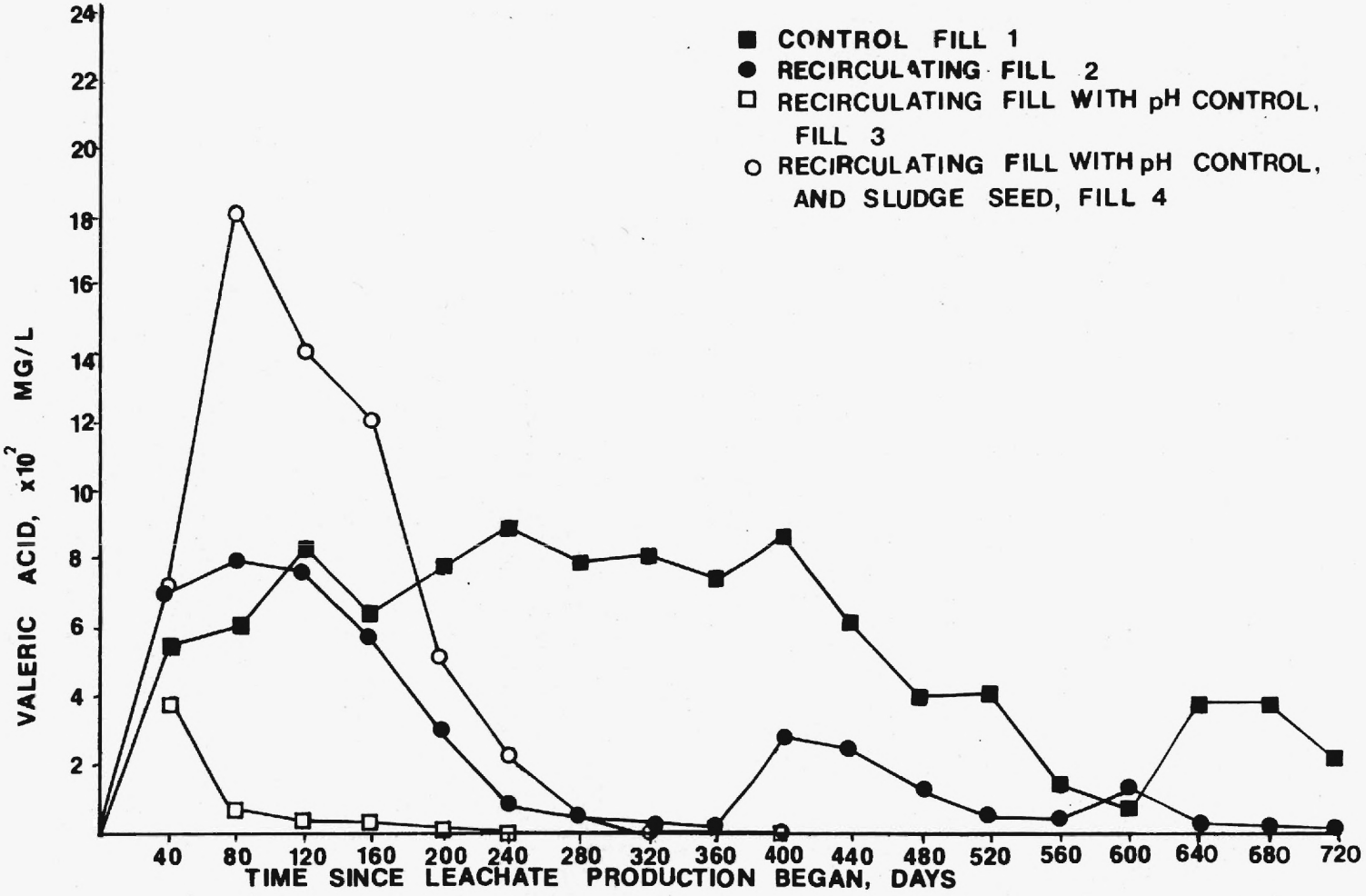

FIGURE 8: VALERIC ACID CONCENTRATION OF LEACHATE

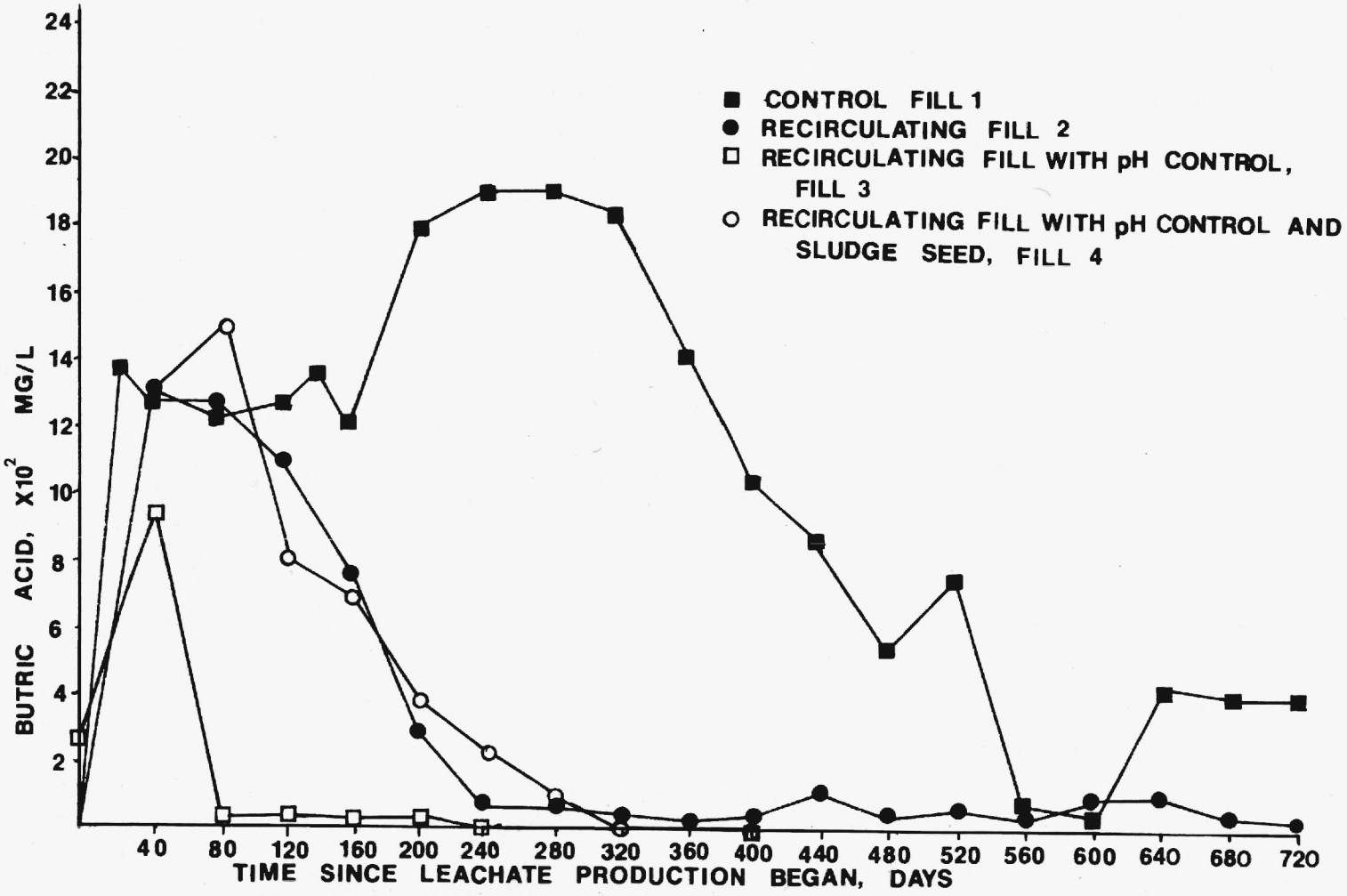

FIGURE 9: BUTYRIC ACID CONCENTRATION OF LEACHATE

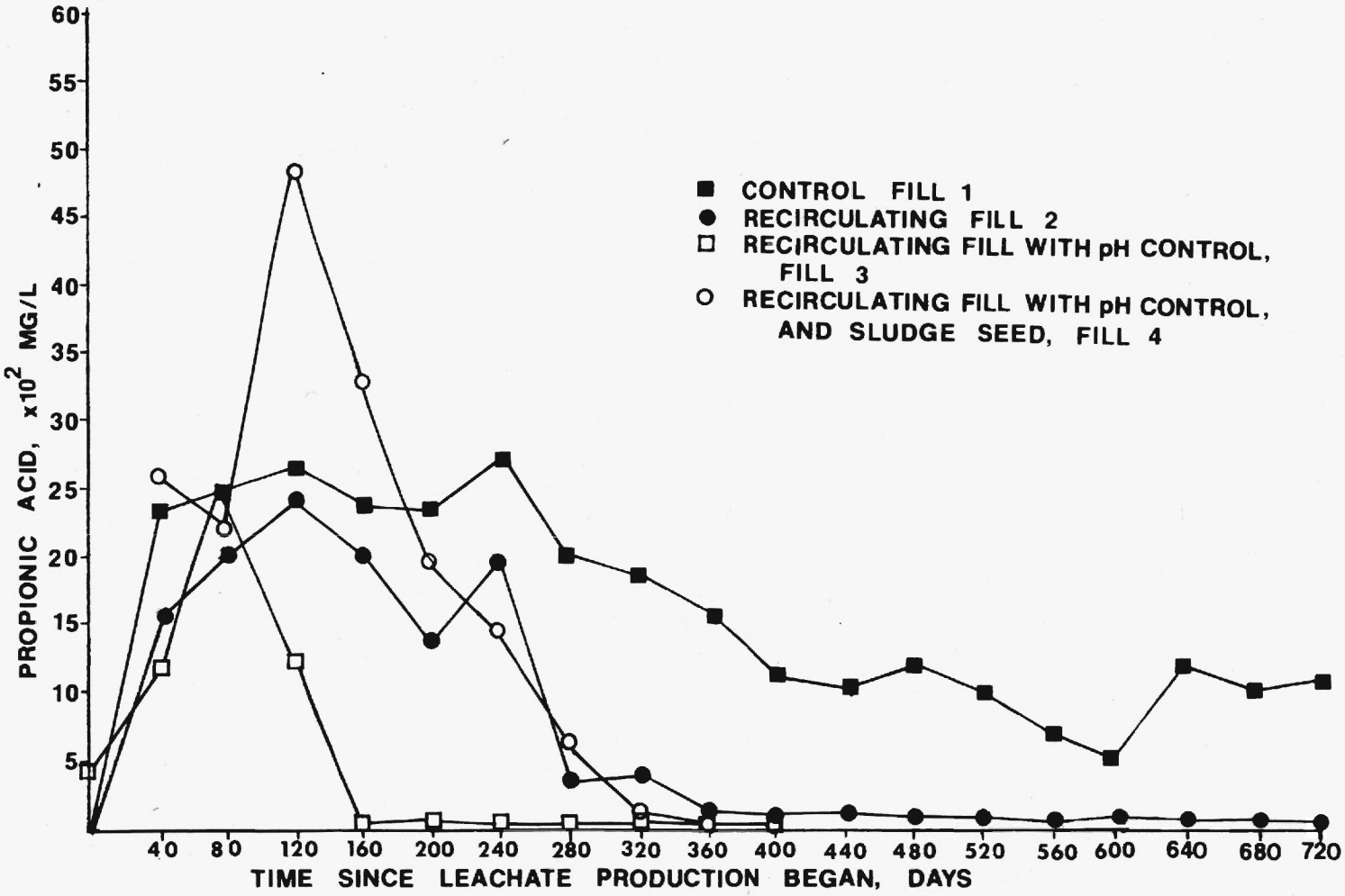

FIGURE 10: PROPIONIC ACID CONCENTRATION OF LEACHATE

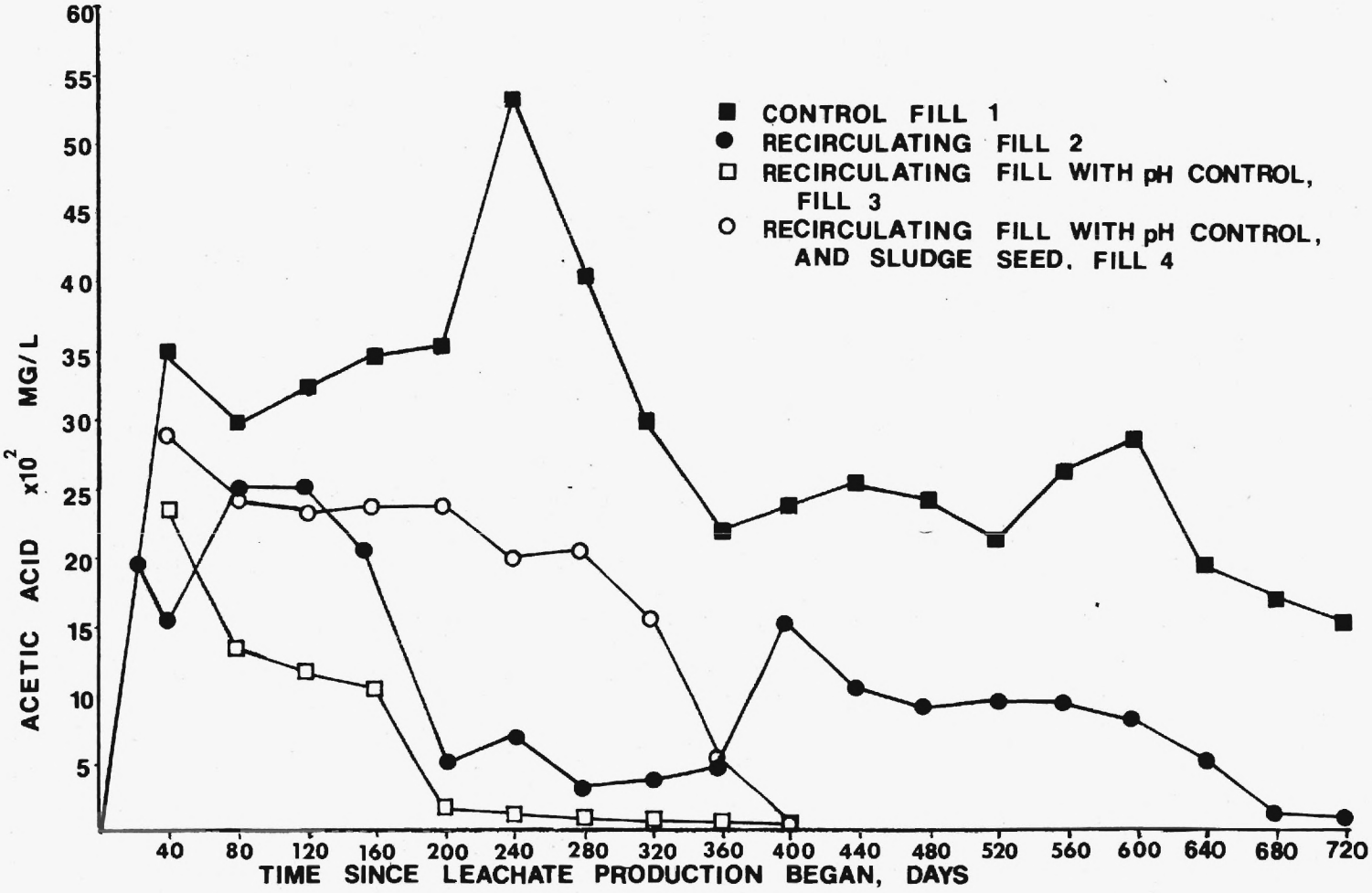

FIGURE 11: ACETIC ACID CONCENTRATION OF LEACHATE

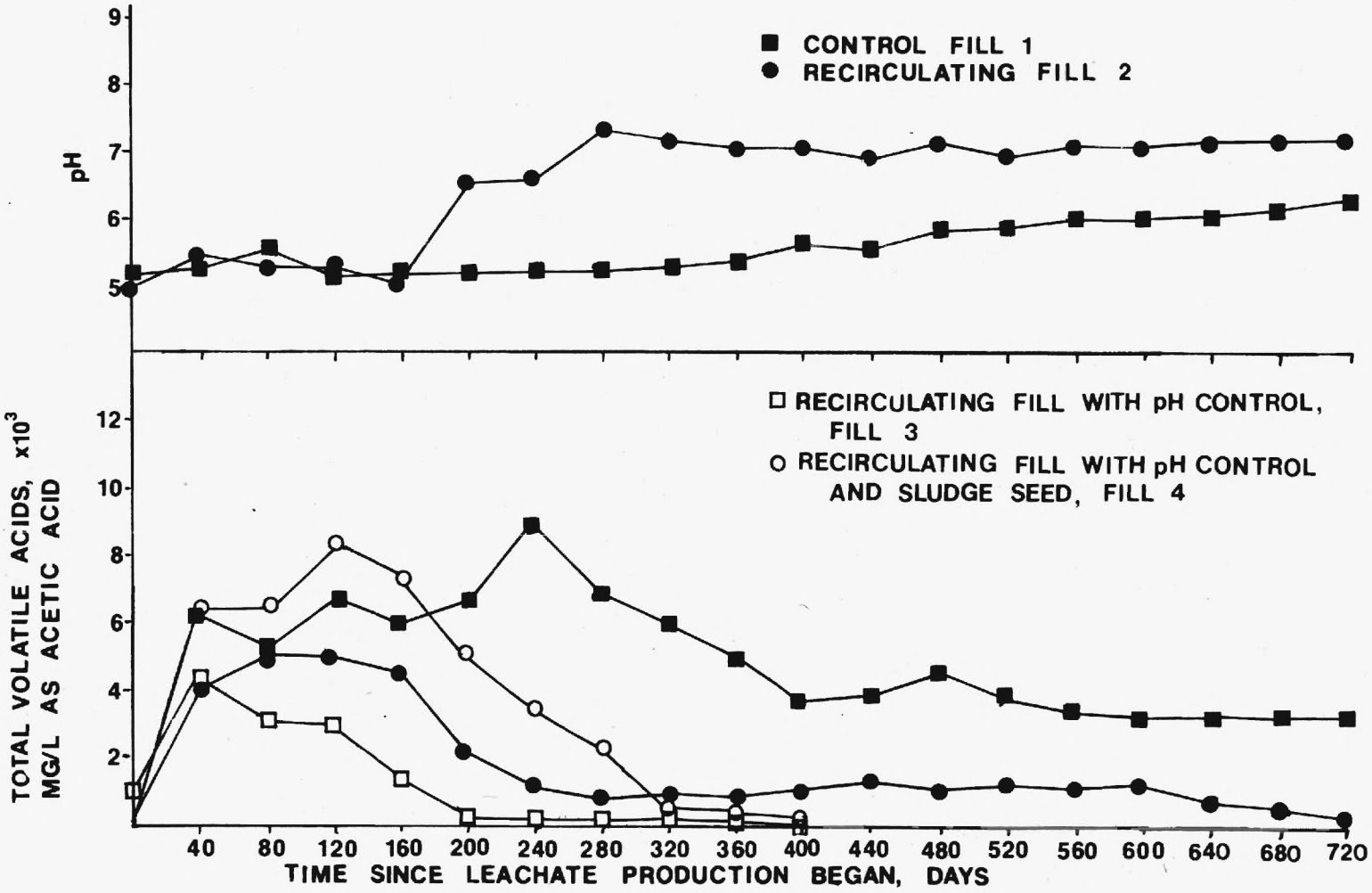

FIGURE 12: pH AND TOTAL VOLATILE ACID CONCENTRATION OF LEACHATE

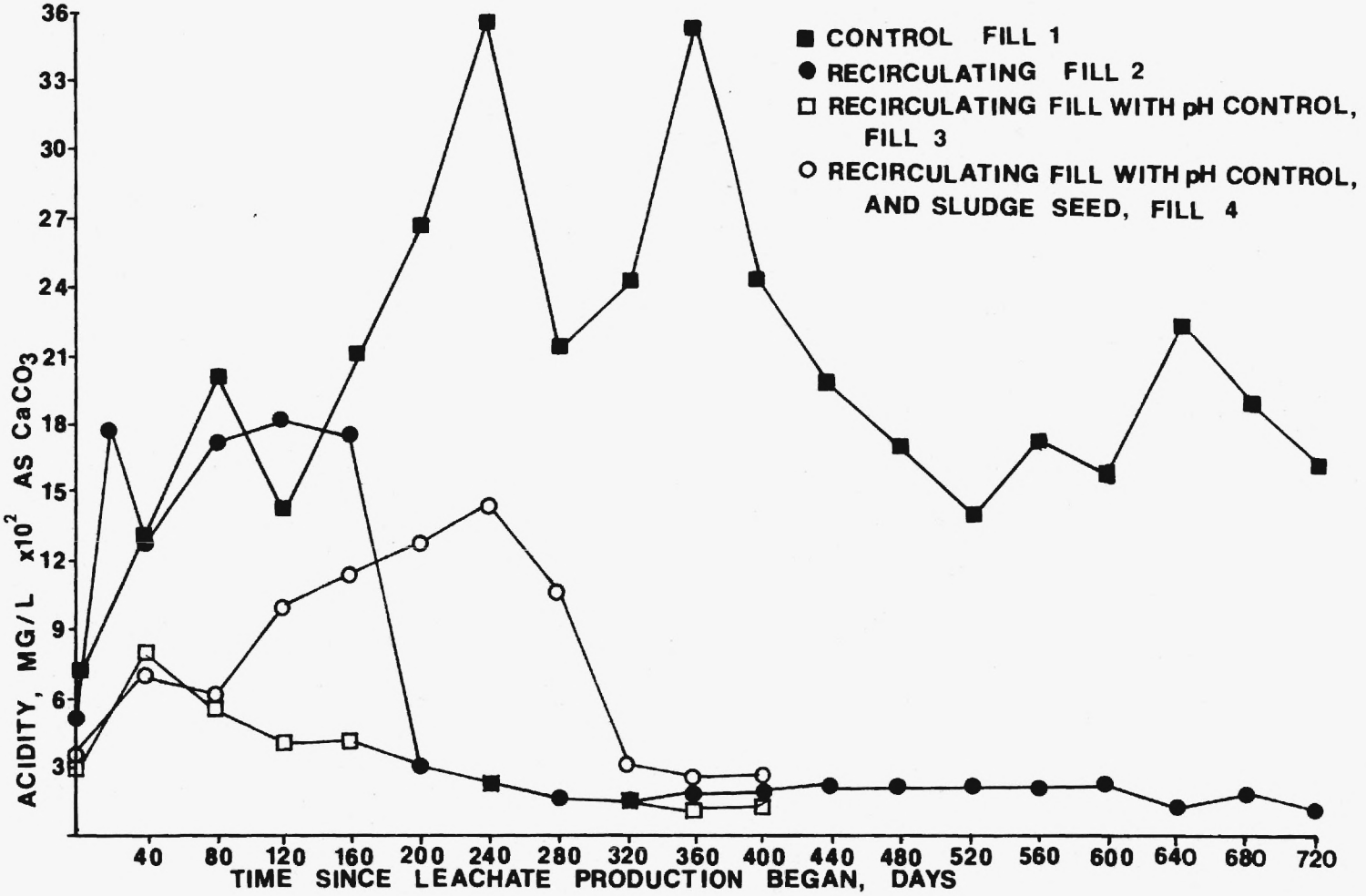

FIGURE 13: ACIDITY OF LEACHATE

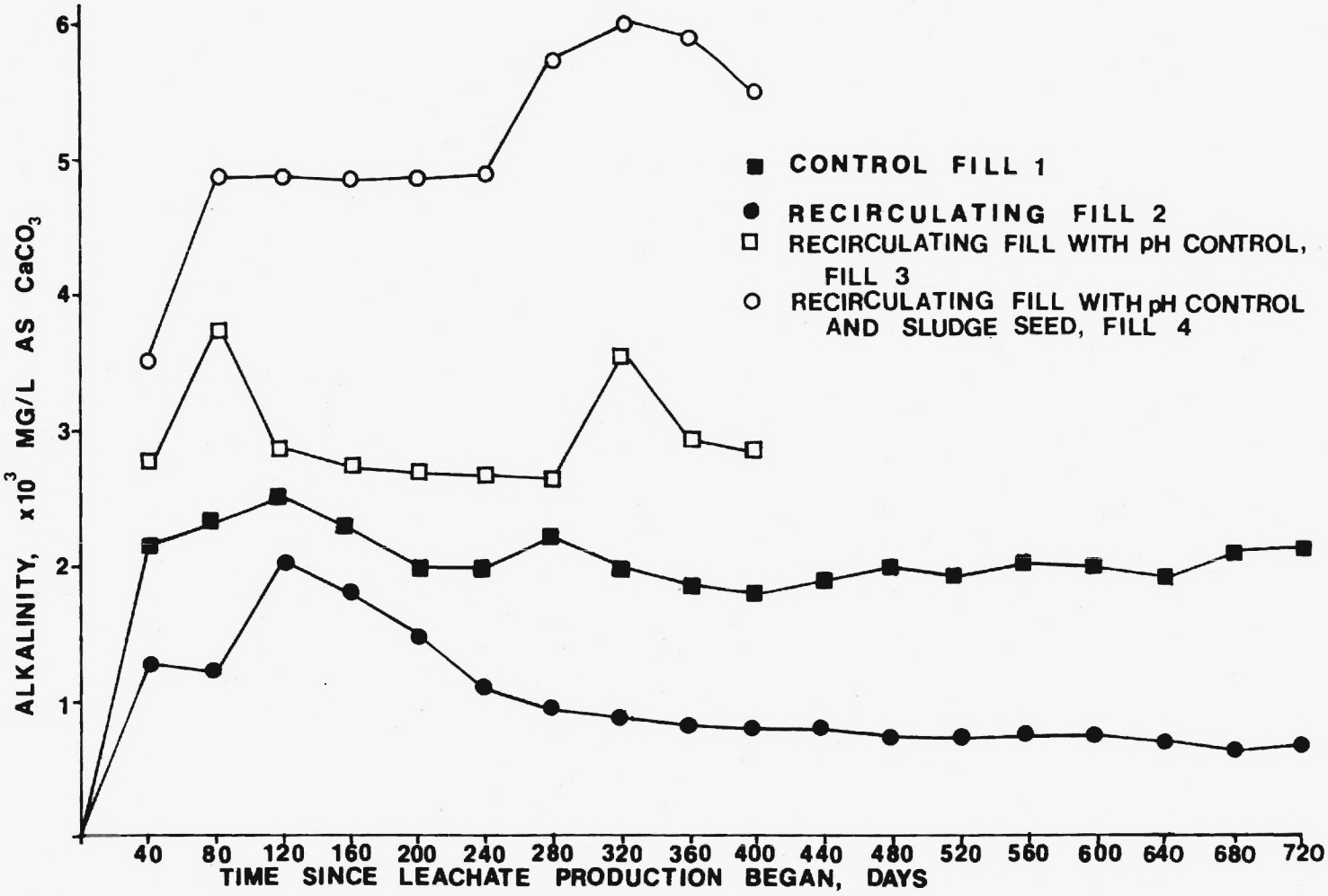

FIGURE 14: ALKALINITY OF LEACHATE

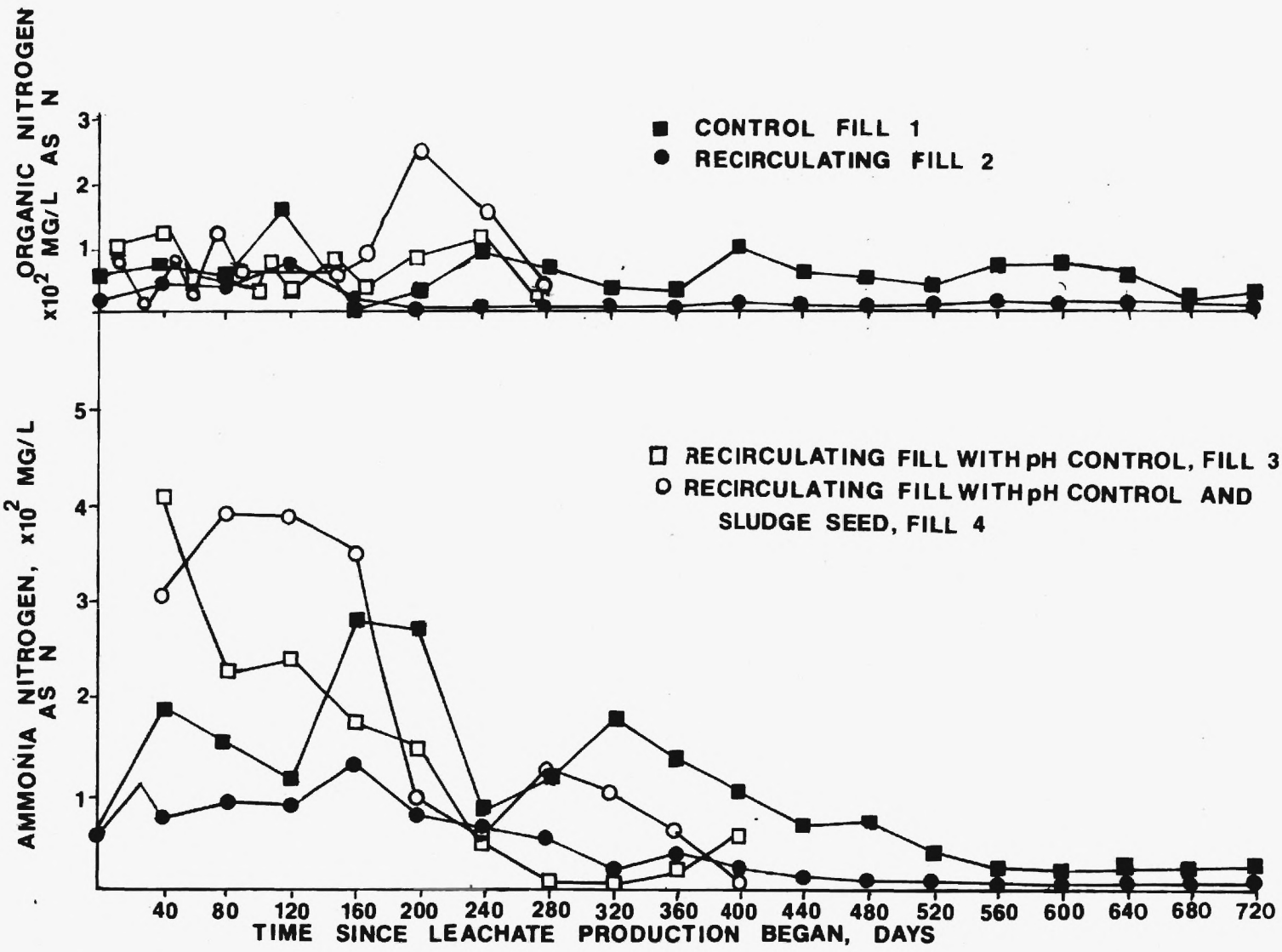

FIGURE 15: CONCENTRATIONS OF ORGANIC AND AMMONIA NITROGEN IN LEACHATE

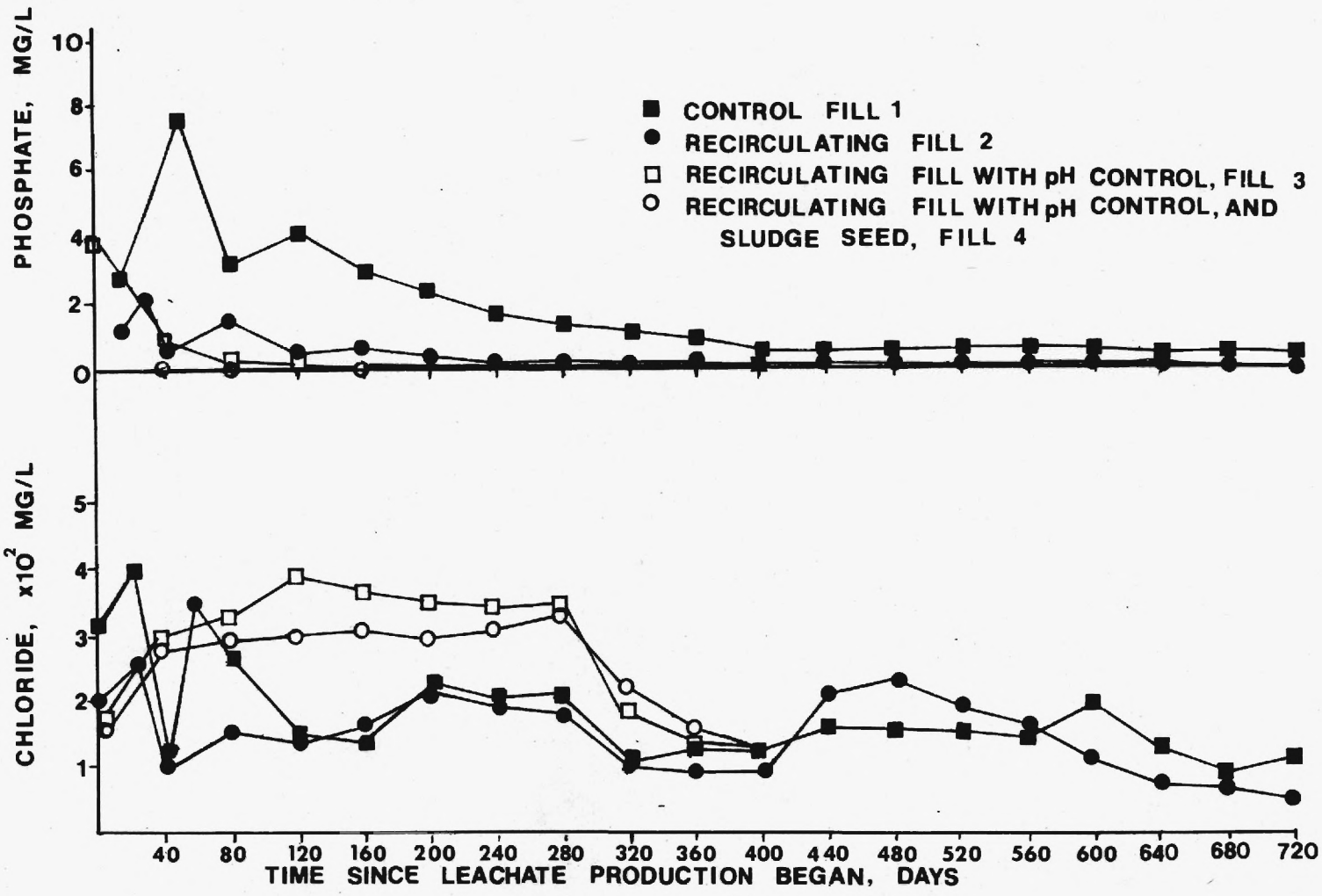

FIGURE 16: PHOSPHATE AND CHLORIDE CONCENTRATIONS OF LEACHATE

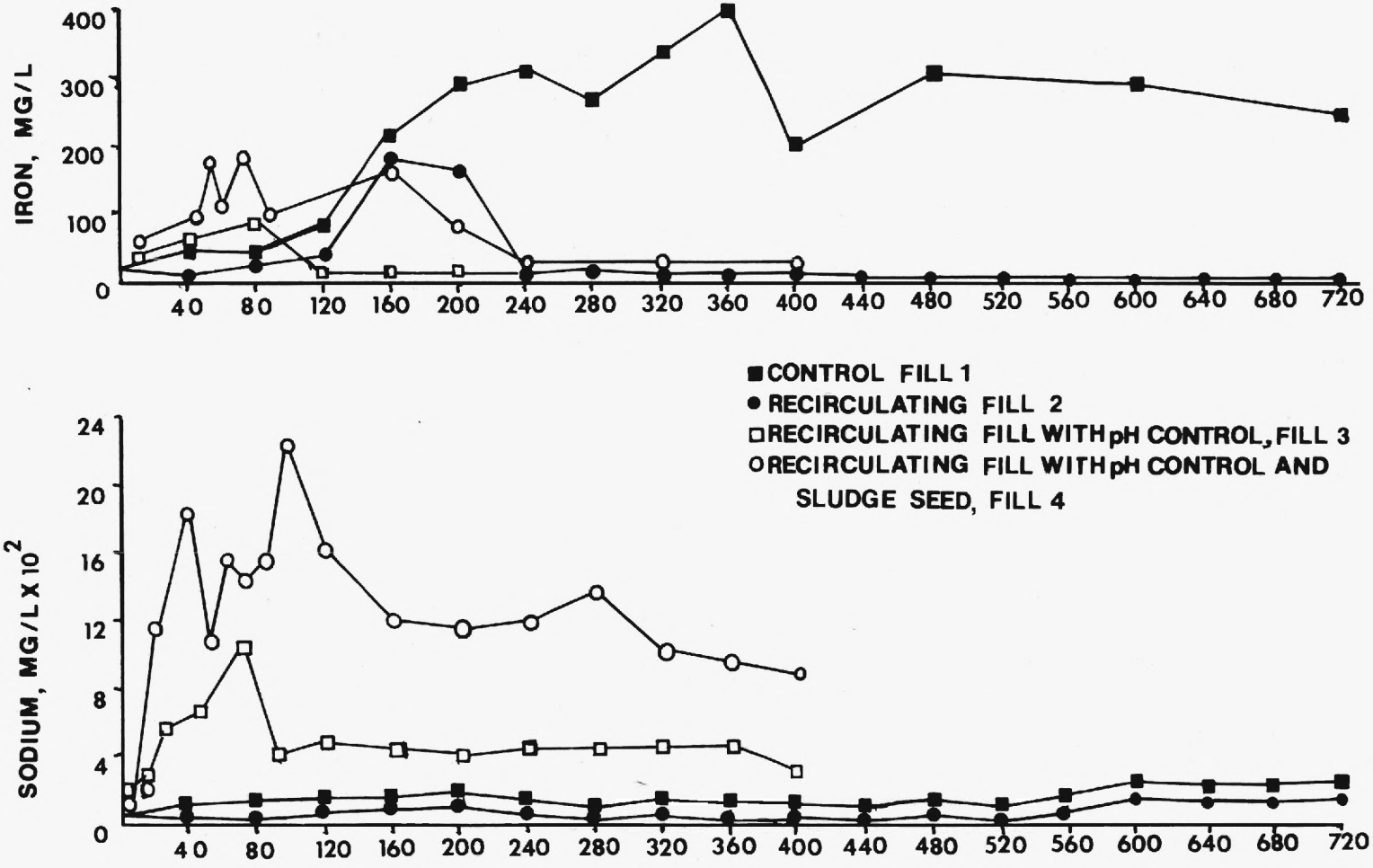

FIGURE 17: IRON AND SODIUM CONCENTRATIONS OF LEACHATE

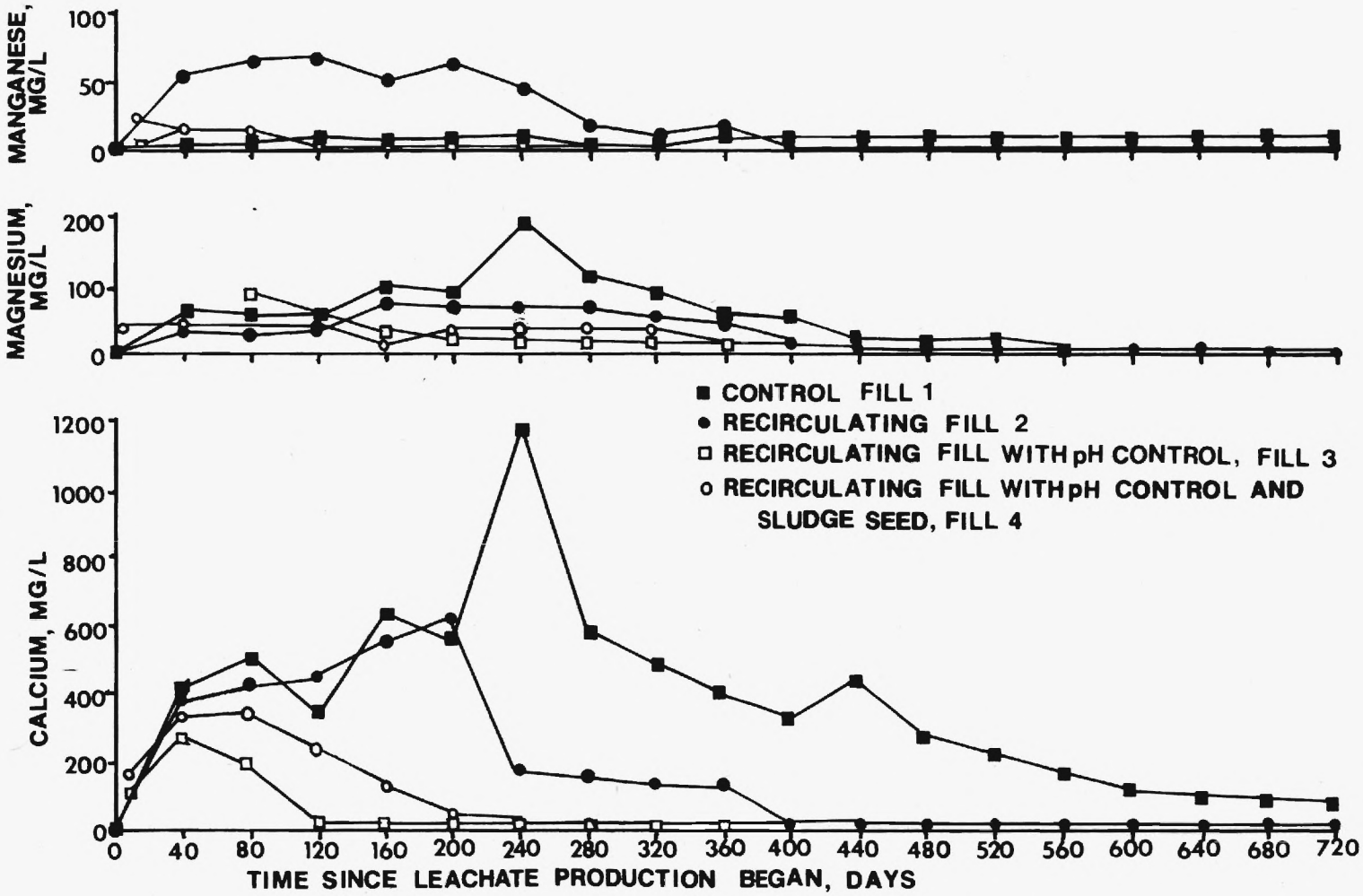

FIGURE 18: MANGANESE, MAGNESIUM, AND CALCIUM CONCENTRATION OF LEACHATE

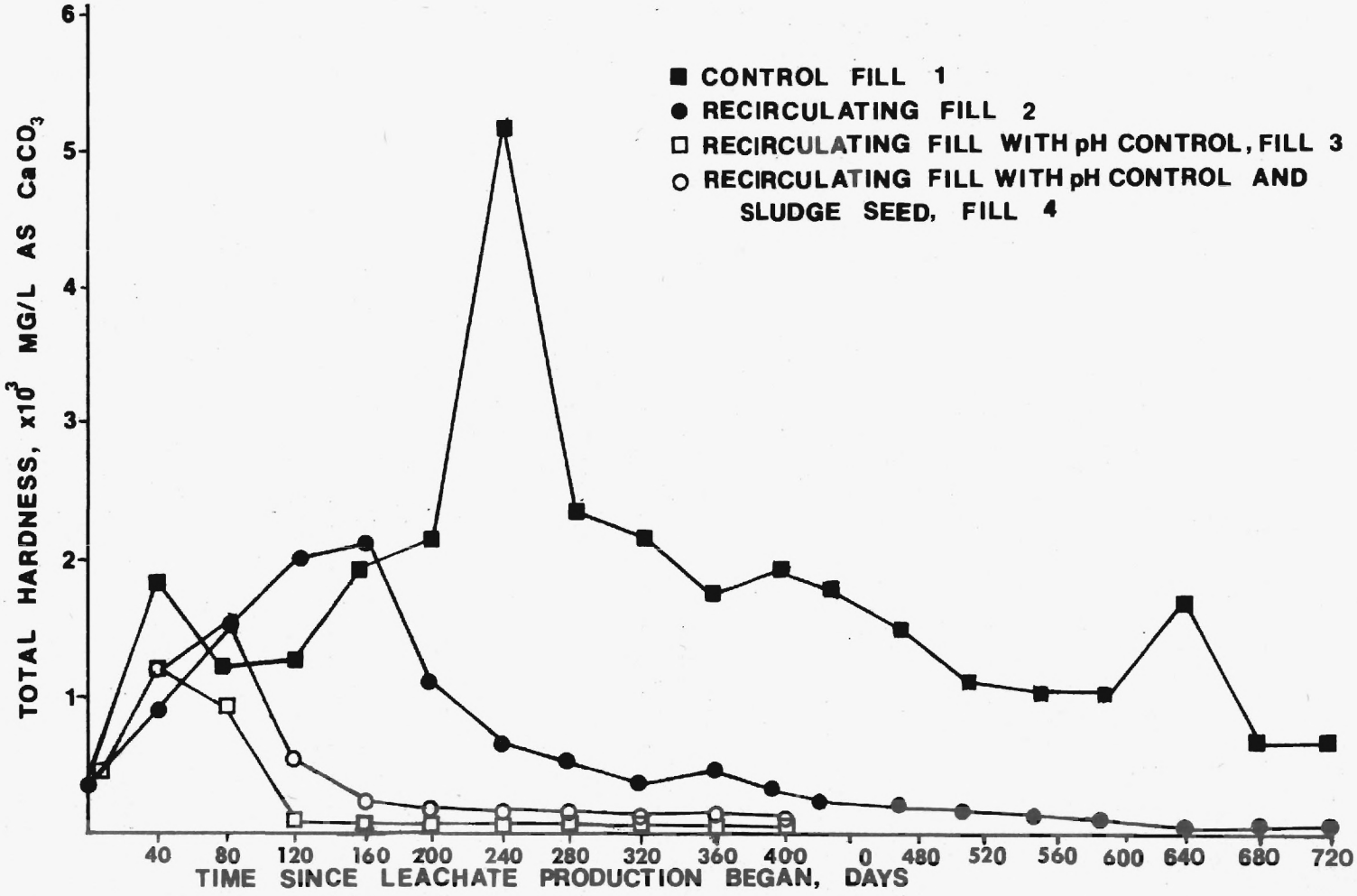

FIGURE 19: TOTAL HARDNESS OF LEACHATE

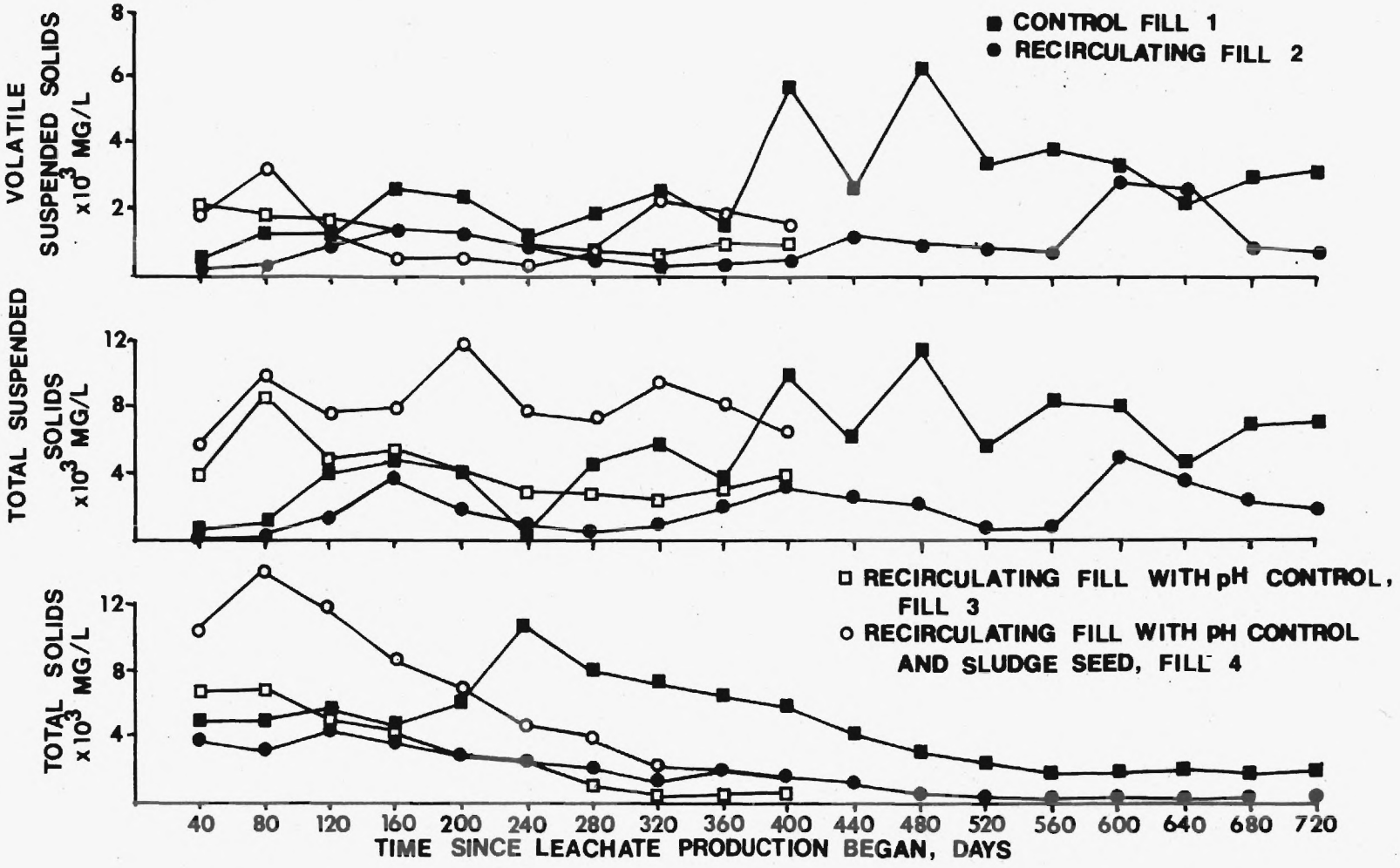

FIGURE 20: SOLIDS CONCENTRATION OF LEACHATE

Neutralization during Phase II

Daily and cumulative quantities of sodium hydroxide used for neutralization during Phase II are graphically represented in Figure 21 together with the corresponding daily pH readings. At the end of 400 days, Fill 3 tended to level off at a value of 1020 grams of sodium hydroxide added and a pH of 6.9. On the other hand, Fill 4 continued to rise steadily with 2520 grams of sodium hydroxide added after 155 days of leachate production and an adjusted pH of 7.4.

Gas Analysis during Phase II

Data showing the relative amounts of carbon dioxide, nitrogen and methane are displayed in Table 13. Fill 3 had a substantially larger percentage of both carbon dioxide and methane at an early stage thus indicating the more rapid establishment of methane-forming bacteria and their continued growth.

Analysis of Raw Primary Sludge Used in Seeding Fill 4 During Phase II

Analysis on the raw primary sludge used to seed Fill 4 included; total solids, hardness, volatile acids, ammonia and organic nitrogen, nitrate, chloride, phosphate, calcium, magnesium, manganese, sodium, iron, potassium, and zinc. The tabulation of the data is presented in Table 14. These tests were used to ascertain the nutrient quality, pollutional load, and possible inhibitory effect of the sludge.

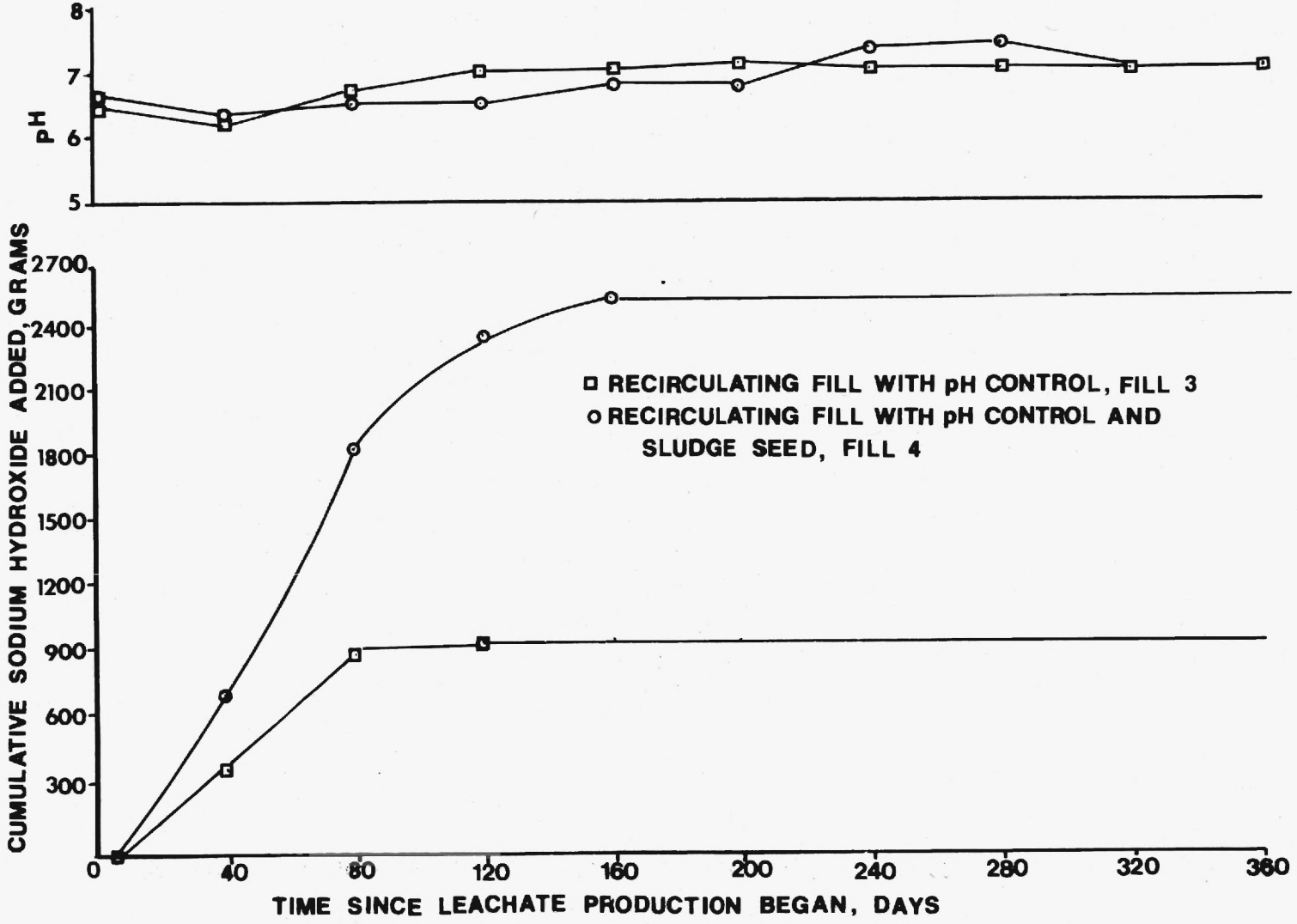

FIGURE 21: ADDITION OF NEUTRALIZING AGENT, SODIUM HYDROXIDE, DURING PHASE II

Table 13

Gas Analysis from Phase II Leachate Columns

Gas Constituent	Percent Concentration in Fill 3*					Percent Concentration in Fill 4**				
	7th week	12th week	32nd week	44th week	58th week	7th week	12th week	32th week	44th week	58th week
Carbon Dioxide	22.0	18.0	6.0	6.0	2.0	2.6	7.4	2.0	8.4	6.4
Nitrogen	33.2	32.5	36.0	40.0	26.0	47.6	49.1	40.0	21.4	24.5
Methane	19.5	25.4	22.0	27.0	2.0	0.0	7.3	2.0	27.1	16.0

*With raw sludge seed.

**Without raw sludge seed.

Table 14

Analysis of Raw Primary Sludge Seed Added to Fill 4 During Phase II

Sludge Constituent	Concentration	Sludge Constituent	Concentration
Total Organic Carbon, mg/l	3,300	Organic Nitrogen, mg/l as N	14
Total Suspended Solids, mg/l	57,850	Nitrate, mg/l as NO_3	0.91
Volatile Suspended Solids, mg/l	33,400	Chlorides, mg/l as Cl	27.6
Total Solids, mg/l	63,100	Phosphates, mg/l as PO_4	7.0
Hardness, mg/l as $CaCO_3$	582	Calcium, mg/l as Ca	138
Acetic Acid, mg/l	6,830	Magnesium, mg/l as Mg	25
Propionic Acid, mg/l	815	Manganese, mg/l as Mn	0.
Butyric Acid, mg/l	600	Sodium, mg/l as Na	50
Valeric Acid, mg/l	290	Iron, mg/l as Fe	75
Ammonia Nitrogen, mg/l as N	361	Potassium, mg/l as K	132
		Zinc, mg/l as Zn	0.05

CHAPTER IV

DISCUSSION

The sanitary landfill method of solid waste disposal depends largely upon anaerobic biological activity to stabilize the decomposable fractions of refuse. The anaerobic process proceeds primarily through two phases with one group of organisms breaking down the larger organic molecules into short-chained organic acids (acid fermentation), and the short-chained acids being subsequently converted to a carbon dioxide and methane by another group of organisms (methane formation).

The methane formation phase is generally considered the rate controlling step in the anaerobic process since it proceeds at a much slower rate and requires a higher degree of environmental control than acid fermentation. The greatest majority of methane forming organisms require strictly anaerobic conditions and a near neutral pH. If acid production exceeds the rate of methane formation to an extent greater than the capacity of the system to buffer the acids produced, the pH will drop below the level at which the methane producers can survive and the methane forming phase of the process will cease to function efficiently. In a properly operating anaerobic system, however, the production of volatile acids will rise initially to a peak value and then decrease. Changes in the concentration of the individual volatile acids will also occur. The pH of the system will decrease during the increase in volatile acids and will then rise steadily while the volatile acids diminish.

The effects of leachate recycle on producing a more favorable anaerobic environment in a sanitary landfill were examined for 720 days during Phase I of this study. Phase II consisted of inducing more favorable conditions

for anaerobic digestion by maintaining the pH in both newly constructed fills near neutral and also by seeding one fill (Fill 4) with primary sewage sludge. The significance of the trends observed in leachate quality and landfill settlement have been discussed as they relate to landfill stabilization and potential environmental pollution.

Effects of Recirculation, pH Control, and Sludge Seeding on Leachate Quality

Leachate recirculation has been shown to markedly reduce the concentrations of readily decomposable pollutants emitted in the leachate from a refuse landfill. Part of the discussion will deal with the continuation of the initial recirculation study. In addition, two new recirculation fills will be compared. The object of this comparison was to determine whether with proper pH control and recirculation the landfill could be better managed to further accelerate waste stabilization. The results indicated this to be the case due to the development of a more active anaerobic population in a shorter time interval. This more rapid development was attributed to the more favorable environment caused by control of the pH near neutral.

The Phase II study was also designed to determine the effects of raw primary sludge seed on a recirculation fill with pH control. Both of the Phase II fills had pH control, while only one was seeded with raw primary sludge. As a result of the seeding and additional nutrients added with the raw sludge, a more rapid and larger production of volatile acids and organic pollutants was observed.

Recirculation of leachate by the three fills was expected to be nearly equal in quantity and recycle interval. This was found not to be the case, possibly due to varying construction techniques. However, since the

data confirmed the initial hypothesis, the discrepancy in recirculation was not considered to be of controlling importance. Differences in frequency of recirculation apparently did not adversely affect the amount of biological action occurring in the fills within the time period considered during the studies. The total leachate recycled during the study period of Phase I was about 150,000 gallons and about 100,000 gallons for Phase II.

Volatile Acids and pH

When dealing with an anaerobic system such as a sanitary landfill, the concentration of volatile acids can be one of the most important indicator parameters. These low molecular weight fatty acids (acetic, propionic, butyric, and valeric) are very diagnostic of the degree of stability of the anaerobic process. Figures 8 through 11 show the behavior of these acids for both Phase I and Phase II of the study.

Phase I

During Phase I there was an early rise in volatile acids concentrations with acetic acid being the most abundant. A reduction in acetic and propionic acids began at about 160 days preceded by butyric and valeric acids at about 100 days in Fill 2. This decrease in volatile acids was accompanied by an increase in pH from 5.3 to 6.2 at about 160 days. The reduction in volatile acids in Fill 1 began at about 280 days after which time the acids decreased steadily but without a corresponding increase in pH.

At about 240 days, the butyric and valeric acid concentrations in Fill 2 had decreased dramatically followed by acetic and butyric acids at about 280 days. The low volatile acids concentrations at this time resulted in an increase in pH to 7.1. The total volatile acids in Fill 1 decreased

gradually during the 720-day study period from a maximum of 9300 mg/l at 228 days to 3070 mg/l; Fill 2 concentrations decreased from a maximum of 5818 mg/l at 96 days to 105 mg/l thereby indicating that leachate recycle was beneficial to the more rapid removal of pollutants from the leachate.

Phase II

After an initial peak at about 40-80 days, the volatile acids concentrations in Fill 3 decreased rapidly to consistently low values with the higher homologues preceding the shorter chain acids in reaching stability in concentration. When the pH in Fill 3 had been adjusted to 6.81 at 52 days, pH control was terminated. Thereafter, the total volatile acids concentration decreased from 5105 mg/l (at 45 days) to 115 mg/l at 183 days at a more rapid pace and in less time than indicated previously for Fill 2. The pH control provided by external neutralization had apparently created a more favorable environment for methane fermentation and an increased rate of stabilization.

For Fill 4, the total volatile acids concentration peaked at about 120 days after which time the acids steadily decreased to low levels similar to the other recycled fills. The maximum total volatile acid concentration in Fill 4 was 8535 mg/l or higher than experienced in Fill 3 indicating that the seed of raw primary sewage sludge accelerated acid fermentation and probably also added to the reservoir of readily available organic material in the fill. Here then pH adjustment was required for about 160 days when a pH of 6.65 was achieved. Accordingly, about 2520 grams of sodium hydroxide were added to Fill 4 as compared to 1020 grams to Fill 3.

As observed for Fills 1 and 2, the concentrations of butyric and valeric acids in Fill 3 decreased to low levels (at about 80 days) again prior to

propionic (at about 160 days) and acetic (at about 200 days) thereby indicating the sequential pattern of conversion. Similarly, butyric and valeric acids decreased to their low levels in Fill 4 in about 320 days followed by propionic and acetic acids at about 360 and 400 days respectively.

Comparison of the results for the four fills indicated that recirculation enhanced the removal of volatile acids from the leachate and that in the absence of such a procedure, the leachate continued to contain relatively high volatile acids concentrations even after 720 days of study.

Organic Pollution Parameters (BOD, COD and TOC)

As could be expected, BOD, COD and TOC followed the same removal trend as the volatile acids. In each fill, the peak concentrations occurred at approximately the same time and decreased correspondingly.

Phase I

The concentration of BOD, COD and TOC for Fill 2 had decreased to relatively low constant values in about 300 days whereas in Fill 1, after reaching a maximum, these parameters decreased gradually. The BOD, COD and TOC maxima were 13,400 mg/l, 18,100 mg/l and 5000 mg/l versus 10,100 mg/l, 10,400 mg/l and 2,789 mg/l for Fills 1 and 2 respectively.

Phase II

Recirculation with pH control again resulted in a more rapid decrease in pollutional characteristics and as measured by BOD, COD and TOC reached consistently low levels at about 120 and 400 days for Fills 3 and 4 respectively. Apparently the influence of the raw seed sludge was again indicated and the delay in neutralization for about two weeks caused a temporary promotion of acid conditions which delayed the desired production of methane

from the volatile acids. However, when pH control had become effective, a dramatic reduction in all pollutional parameters occurred.

Acidity and Alkalinity

During these investigations, the predominant source of acidity was the volatile acids so that acidity increased or decreased as the volatile acids increased or decreased. Likewise, the alkalinity was reflected by the association of cations and anions present in the system which under normal operation would include the carbon dioxide-bicarbonate-carbonate buffer system at neutral pH and the volatile acids buffer system at low pH. Therefore, direct relationships could be anticipated between the acid-base pairs present, i.e., volatile acids, ammonium, calcium (and magnesium), and sodium (particularly when added for pH control).

Phase I

The acidity of Fill 2 decreased dramatically at about 200 days corresponding to decreases in volatile acids, BOD, COD and TOC. At the end of the study period, the acidity of Fill 2 was 140 mg/l while that of Fill 1 remained high at 1550 mg/l.

The alkalinity in the Fill 1 leachate remained relatively constant during the study period at about 2200 mg/l. The alkalinity in the Fill 2 leachate decreased gradually with time as a consequence of dilution and other reactions within the fill. The alkalinity of Fills 1 and 2 reflected the magnitude of the buffer capacity established at either acid or neutral pH.

Phase II

The acidity of Fills 3 and 4 changed as expected with changes in organic pollutant concentrations in the leachate. The impact of the raw seed sludge on acid production was reflected in the increase in acidity for Fill 4. The

initial acidity in Fills 3 and 4 was generally less than that of Fills 1 and 2 due to the addition of the neutralizing agent (NaOH) after two weeks.

The alkalinity values for Fills 3 and 4 indicated the influence of base additions for pH control and thus were of greater magnitude than for Fills 1 and 2. Some fluctuation was noted which is also illustrated in similar changes in sodium concentration (Figure 17). This latter concentration remained less than the presumed cation toxicity level of 8000 mg/l and therefore possible toxic effects was not considered an issue.

Nitrogen and Phosphate

Phase I

The concentrations of organic and ammonia nitrogen were substantially lower in the Fill 2 leachate than in that of Fill 1. The organic nitrogen decrease tended to precede the decrease in ammonia nitrogen as a consequence of sequential conversion, however, the concentrations were changed also as a consequence of biological utilization and/or dilution. Whereas the organic and ammonia nitrogen concentrations in the Fill 1 leachate were 26 mg/l and 12 mg/l respectively at the end of 720 days, measured values for Fill 2 decreased to zero on several occasions.

The initial phosphate concentrations were relatively high in both fills as soluble phosphate was leached by the initial water additions. The ensuing concentrations reflected higher values for Fill 1 than Fill 2 probably as a consequence of greater biological utilization and/or dilution in the latter.

Phase II

After initial high values of both organic and ammonia nitrogen, the concentrations did not decrease in Fill 4 until about 200 days had elapsed whereas in Fill 3, a gradual decrease occurred. The raw seed sludge addition

to Fill 4 again had its impact on the nitrogen content with greater initial concentrations in the Fill 4 leachate than in that from Fill 3. However, with time these concentrations decreased to similar values.

Both Fills 3 and 4 seemed to be utilizing the phosphate present and more rapidly than indicated for Fills 1 and 2. This again supported the likelihood that Fills 3 and 4 were more biologically active than Fills 1 and 2 at the start as a consequence of the initial pH control.

Metals and Hardness

Phase I

For the first 160 days, the concentration of iron was similar and increased steadily in both Fill 1 and Fill 2 probably as a consequence of the emergence of acid conditions (some corrosion of piping) and a more reducing condition in the fills. However, after 160 days, the iron concentration in the Fill 2 leachate decreased sharply as the pH increased from about 5.2 to 7.2. It is possible that as the pollutants were removed from Fill 2, the environment became less reducing permitting the oxidation and precipitation of iron from the leachate. Such a possibility was evidenced by a brownish color in the leachate recycle at this time for Fill 2 as compared to the greenish color of the Fill 1 leachate. At about 430 days, the iron concentration was essentially zero in the Fill 2 leachate whereas the Fill 1 leachate remained high and at 240 mg/l at the end of the 720-day study period.

In the early stages of the study, the manganese concentration was higher in the Fill 2 leachate which may also have reflected a more reducing environment than in Fill 1 with the insoluble manganese being reduced to the soluble manganous form. In fact, the Fill 1 leachate never reached a manganese concentration above 20 mg/l throughout the 720 days of the study while a maximum of

93 mg/l was obtained for Fill 2 at 140 days. As with iron, the concentration of manganese in Fill 2 began to decrease as the pH rose and thereafter reached a relatively low value of 10 mg/l at 249 days. However, unlike iron, manganese is relatively soluble up to pH 9 and thus soluble throughout the pH range obtained in the study. As a consequence, it was possible that the decrease in soluble manganese might have been due to a lessening of the reducing conditions within Fill 2 as stabilization progressed. At 720 days, the manganese concentration in Fill 1 was 2.5 mg/l while it reached essentially zero at about 500 days in Fill 2.

Sodium concentrations from both fills were low throughout Phase I. Concentrations of 210 mg/l and 120 mg/l were recorded for Fills 1 and 2 respectively at the end of the study period. In contrast, the concentrations of calcium and magnesium, although similar for about the first 200 days, became somewhat dissimilar thereafter probably as a consequence of operational modes and the influence of rainfall. The relatively large rainfall between 200 and 220 days of the study period washed out a considerable concentration which appeared subsequently as a slug in the leachate from Fill 1. This rainfall also subsequently caused some dilution of concentration in the Fill 2 leachate. In addition, it is possible that reductions in concentration might have been due to the opportunity for ion exchange and the formation of organometallic complexes which would have been more possible in Fill 2 than in Fill 1. This exchange or complexation being pH-Eh dependent would be difficult to predict because of the differences in operation and degrees or state of stabilization at any one period of analysis.

Phase II

The iron concentration between Fills 3 and 4 varied considerably after an

initial period of 45 days. However, after 80 days the concentration in Fill 3 decreased to very low values again as the pH increased from 6.2 to 7.05 as a a consequence of neutralization and/or effective biological stabillzation. The iron in the Fill 4 leachate did not decrease to low values until about 240 days had elapsed and when the pH increased from 6.7 to 7.4. At these times, there was a noticeable change in leachate color from greenish-brown to light brown. Therefore, it is likely that with the decrease in volatile acids and increase in pH, a more oxidizing environment prevailed with a concomitant conversion of the ferrous to the ferric form of iron.

Although manganese has similar chemical characteristics as iron, it appeared that little soluble manganese was present in either Fill 3 or Fill 4 during the study period with concentrations less than 25 mg/l. Similarly, the concentration of magnesium in both fills was low and ranged between 12 and 15 mg/l. Recycle of the leachate tended to maintain relatively constant concentrations of both manganese and magnesium.

Calcium concentrations in Fill 3 were lower than in Fill 4 during the initial 200 days after which time they were low and essentially constant. Compared to the Phase I analyses, concentrations in the Phase II fills decreased much more rapidly which again may have been a consequence of the neutralization procedures employed and possible ion exchange or complex formation. Neutralization also increased the sodium level in Fills 3 and 4 in accordance with the amount of caustic soda added for pH control (Figure 21). Accordingly, Fill 4 received and maintained larger concentrations; the maximum of 2400 mg/l at about 120 days was not considered sufficient to impart a toxic effect.

The heavy metals copper, zinc, nickle and lead as well as chromium were also analyzed for during each phase of the study. Except for measurable concentrations of zinc in Fills 1 and 4, these appeared only in trace quantities.

A concentration of 42.5 mg/l zinc was detected at 560 days in Fill 1 which decreased to 9 mg/l at the end of the study period. The zinc concentration in Fill 4 reached its peak of 22 mg/l at 73 days and then gradually decreased to zero at 220 days. It is possible that the delayed appearance of zinc was a consequence of initial precipitation in the fills as sulfide and then later released as the environment became less reducing and the sulfides were oxidized.

The total hardness in the leachate from each fill reflected the pattern of divalent cations present. Of particular significance was the calcium which primarily determined the reduction in hardness during both phases of the study.

Solids

Phase I

Although it was difficult to attach meaningful interpretation to the solids data because of the dependence on the various uncontrollable physical and chemical processes occurring at any one time, the total solids in the Fill 2 leachate reduced to 700 mg/l as compared to 2100 mg/l for Fill 1 at the end of the study period. As supported by the greater reduction in pollutional parameters, the solids concentration could also be considered to reflect a greater degree of stabilization with leachate recirculation.

Phase II

Solids data on the Phase II fills were less conclusive except to reflect the contribution of caustic soda to the total solids and a seemingly more rapid decrease with time when compared with Fills 1 and 2. Again, interpretive analysis was curtailed by the stage of operation and limitations on obtaining a representative and meaningful sample.

Effects of pH Control on Landfill Stabilization

The quality of the pH controlled leachate and the increased settling rate (Table 6) observed in the recirculating fills emphasized the fact that a more active anaerobic biological system was established in the recirculating fills. This was especially apparent when Fill 2 and Fill 3 were compared to Fill 1. The fill with recirculation, pH control, and added primary sludge (Fill 4) was not initially as effective in improving the quality of leachate due to the conflict encountered between pH control which would abet anaerobic digestion, and primary sewage sludge which would and did create an environment most beneficial to volatile acid forming bacteria and therefore initially unfavorable to methane forming bacteria. Therefore, raw sludge seeding did not initially aid in the anaerobic stabilization process, and in fact caused it to be delayed. This was caused by the delay between seeding the fills with raw primary sludge and initiating the neutralization process; a delay of approximately two weeks.

A comparison of the initial refuse composition in Fill 3 and Fill 4 with the composition of samples taken from the fills at the end of the study period (Table 5) supported the contention that anaerobic digestion and thus stabilization of the organic portion of the refuse had proceeded further in the recirculating fill with pH control (Fill 3) than in fill of Phase I. Also, the recirculating fill with pH control and sludge seed (Fill 4) experienced a larger reduction of its organic portion than the control fill of Phase I. After 720 days of Phase I, Fill 1 had a 2.5 percent reduction in organic carbon and a 7.9 percent reduction in volatile solids. Comparing this to Fills 3 and 4, the reduction in organic carbon was respectively 13.5 percent and 12.7 percent; the volatile solids reduction

was 10.6 percent and 14.6 percent, respectively. Fills 3 and 4 were operated 400 days when tested, while the control and recycle fills were well over 400 days of age. Fill 2 experienced a 21.6 percent reduction in organic carbon and a 25.9 percent reduction in volatile solids. The samples from the Phase I fills were taken from near the surface of the fills and probably did not show as great a decomposition as a sample from near the center. The Phase II fills had samples removed from near the center of each fill and should be fairly representative. However, it was still clear that stabilization was being accomplished more rapidly in the recirculating fills than in the control fill.

Gas Analysis

Gas analyses performed during the study period of Phase II (See Table 13) indicated that there was early development of methane formers in Fill 3 with a constant methane production at about 25 percent by volume until it reduced to about two percent when most of the organic constituents (volatile acids) had been consumed at the end of the study period. In contrast, the rapid development of acid fermentation in Fill 4 delayed methane production until at 44 weeks the methane concentration reached a maximum value of 27.1 percent and the volatile acids decreased accordingly. This delay was also apparent at the end of the study period with methane concentrations of 16 percent still being detected in the gas from Fill 4.

Admittedly, the measurement of gas production and composition was not absolute but was considered to be sufficient to reflect relative activity and support conclusions concerning the intrinsic roles of acid and methane formers during the course of anaerobic stabilization within the fills. Although not measured, a similar response could be presumed for the Phase I fills.

Volatile Acids and BOD as a Measure of Stabilization

Phase I

As discussed previously, the volatile acid concentrations in the recirculated leachate (Fill 2) of Phase I decreased dramatically after 200 days of recirculation. The rapid decline in volatile acids caused a concomitant rise in pH. It was noted that the pH rose quickly from 5.2 to 6.6 and then rose steadily to a high value of 7.4. Thus the pH of the system quickly came within the optimun range (6.6-7.4) for the pH-sensitive methane forming bacteria. As the methane forming phase became established, a stable anaerobic system was produced within the recirculating fill. Because the stabilization of refuse in a sanitary landfill is dependent upon anaerobic biological action, the stable anaerobic system in the recirculated fill naturally promoted the stabilization process. In contrast, the environment within the control fill (Fill 1) never reached pH values optimum for the establishment of a viable methane forming population and thus, during the study period, the control fill never became stabilized to the extent of the recirculation fill.

The dramatic reduction in the leachate BOD during Phase I by recirculation through the fill supported the hypothesis that recirculation increased the rate of refuse stabilization. The BOD of the recirculated leachate by the end of the study period was reduced 99.5 percent from its maximum value. The nonrecirculated leachate of Fill 1 showed a 75 percent reduction from its maximum BOD over the same period. Thus in terms of readily biologically oxidizable organics in the refuse, the recirculation of leachate produced a greater degree of refuse stabilization.

Phase II

During Phase II, the volatile acid concentration of Fill 3 was greatly

reduced after 45 days and this corresponded to an increase in pH from 6.30 at 45 days to 7.00 at 87 days. The methane forming phase became established in Fill 3 as the pH came within the optimum range (6.6-7.40) for the pH-sensitive methane producing bacteria. Because the stabilization of refuse in a sanitary landfill is dependent upon anaerobic biological action, the stable anaerobic system in the recirculated fill with pH control naturally promoted the stabilization process. On the other hand, the fill with recirculation capabilities, pH control, and sludge seeding (Fill 4) reached a favorable pH range only after about 200 days at which time an environment that would enable the establishment of a methane producing population was provided. This delay was due in part to the lag time (two weeks) between sludge seeding and the initiation of neutralization.

In comparing Fill 3 with Fill 2, it was apparent that the former had reached the low level of volatile acid production that the latter reached in about one-half the time, and also had correspondingly higher pH values. This indicated, therefore, that Fill 3 had reached stabilization to the same degree as the recirculating fill, but had accomplished it in half the time.

Values for Phase II BOD varied greatly between Fills 3 and 4. Fill 3 showed a more rapid reduction in this parameter from its peak value at 25 days; by the end of the study period it had been reduced substantially and similar in magnitude to Fill 2 thereby indicating an increased rate of stabilization. Fill 4 displayed a delayed reduction which paralleled the reduction in volatile acids but which was similar to Fill 3 at the end of the study period.

In comparing Fill 3 with Fill 1 and Fill 2, the degree of stabilization as characterized by BOD indicated that Fill 3 was at approximately

the same level in 120 days as Fill 2 was in 280 days and Fill 1 had not reached by in 720 days. Therefore, in terms of readily biologically oxidizable organics in the refuse, Fill 3 produced in a shorter period of time a higher rate of refuse stabilization than Fill 1 or Fill 2 of Phase I. Using the available date, Fill 3 reached low BOD concentrations and therefore the stabilization experienced by Fill 2 in less than half the time. This exemplified the benefits of a pH control and recirculating leachate through a sanitary landfill.

Because ultimate site use is one of the primary concerns when designing a sanitary landfill for solid waste disposal, the rate of refuse stabilization is most important. The ultimate use of many landfill sites must be delayed for years because of continuing settling, gas release, uncertainties about leachate production, etc. However, it now appears that when recirculation and pH control of leachate is practiced, refuse stabilization may be approached in a much shorter period of time. Because the value of the landfill site in terms of ultimate use may be realized sooner, economic conditions may well warrant recirculation and pH control on a large scale.

Effects of Recirculation, Neutralization, and Sludge Seeding on Total Environmental Pollution

Based on the leachate production of Fill 1 of Phase I as presented in Table 10, the total mass of material leached from the control fill during the 720 day test period was calculated. The total mass of materials present in the initial recirculated leachate from Fill 2 at the end of the study was also calculated using the same volume of leachate as was produced by Fill 1. Fills 3 and 4 of Phase II had its concentrations calculated in the same manner as that of Fill 2, using the volume of leachate produced in its 400-day test period. The mass of the various materials was tabulated as indicated in Table 15.

Table 15

Quantities of Materials Leached from Fills 1 and 2 after Phase I and in Fill 3 and 4 after Phase II

Leachate Constituent	Quantity of Material, pounds			
	Fill 1*	Fill 2**	Fill 3***	Fill 4****
COD	3.37	0.05	0.06	0.16
BOD_5	2.26	0.03	0.02	0.05
TOC	1.34	0.17	0.10	0.20
TSS	0.50	0.13	0.09	0.14
VSS	0.21	0.05	0.03	0.03
TS	1.41	0.50	0.25	0.31
Alkalinity as $CaCO_3$	1.51	0.57	1.13	0.60
Acidity as $CaCO_3$	1.10	0.09	0.03	0.05
Total Hardness as $CaCO_3$	0.51	0.07	0.03	0.03
Acetic Acid	1.04	0.05	0.02	0.02
Propionic Acid	0.74	0.02	0.01	0.01
Butyric Acid	0.27	nil	nil	nil
Valeric Acid	0.17	nil	nil	nil
Phosphate as $PO_4^{\blacksquare}$	nil	nil	nil	nil
Organic Nitrogen as N	0.01	nil	0.01	0.01
Ammonia Nitrogen as N	0.005	nil	0.01	nil
Chlorides as Cl^-	0.07	0.05	0.03	0.03
Calcium	0.10	0.01	nil	nil
Magnesium	0.05	0.01	nil	nil
Manganese	nil	nil	nil	nil
Sodium	0.14	0.08	0.06	0.18
Iron	0.16	nil	nil	nil
Potassium	---	---	0.06	0.06
Zinc	---	---	nil	nil
Total Volatile Acids as Acetic Acid	2.08	0.07	0.03	0.03

*See Table 9 for leachate volumes.
**Based on a total volume of 80 (same as total leachate production in Fill 1) gallons and the concentrations at end of study period - 720 days.
***Based on a total volume of 25 gallons and concentrations at end of study period - 400 days.

A comparison of the quantities after the 720 days indicated that a large quantity of the material extracted was attenuated by the anaerobic biological system established in Fill 2 of Phase I. A similar result was indicated for the fills of Phase II in 400 days. From Table 15, the 80 gallons of recirculated leachate from Phase I and the 25 gallons of recirculated leachate with neutralization (Fill 3) could after 720 and 400 days, respectively, be released to the environment with much less total consequence than would be the case with the control (Fill 1) leachate. Therefore, if the leachate from a landfill is contained and recirculated with or without proper pH control (depending upon placement of seed and time of placement) until refuse stabilization is near completion, then it can be released to the environment more predictably and with a much less pollutional effect than leachate from conventially operated fills, or fills with improperly controlled pH as was the case initially with Fill 4.

In many areas where ground water is used for drinking water supplies, the sanitary landfill disposal method has been discouraged because of possible leachate contamination. When landfills are used in these areas, the leachate must be collected, treated, and then discharged to receiving waters. Since the leachate is extremely high in BOD as well as some inorganics, it could severely tax a municipal treatment facility and especially a small private facility. In light of the present data, this problem may be alleviated by recirculating the collected leachate back through the fill by a series of pumps and distributor pipes. As each cell of the fill is completed, the recirculation system could be installed. The leachate could then be recirculated until stabilization of the fill was approached or until the BOD or other pollutional parameters were reduced to levels such that the leachate would be amenable for discharge or for

release to additional treatment depending upon local requirements. This stabilization and/or pollution parameter reduction could be greatly facilitated by neutralization during recirculation of the leachate by means of a pH-actuated reservoir of base. In essence, the landfill itself is thereby used as a controlled anaerobic treatment system.

Assuming that the simulated landfills used in the study can be related to large-scale landfill operations, it appears that recirculated leachate can reach, in a reasonable length of time, a quality suitable for release into noncritical receiving waters. Also, this study indicates that the length of time required to reach the desired quality of leachate can be lessened by neutralization with recirculation of the leachate. Whether such inorganic pollutants as hardness, chloride, calcium, etc. require additional treatment depends upon the condition of the receiving waters and/or regulatory requirements.

It would also be possible to use leachate recirculation (with or without pH control) in combination with external treatment. Since most landfill sites are not near municipal sewage systems, it would be advantageous to use portable package waste treatment plants at the site. However, such plants are not suitable for the treatment of leachate from a conventional landfill because intermittant leachate flow is not conducive to successful operation of such a system. By recirculating the leachate through the portable plant and through the landfill, a constant flow could be maintained and adjusted to suit the capacity of the plant. The plant effluent could be discharged intermittantly to the receiving waters at the most advantageous times. When the landfill became stable (time to reach stability reduced by leachate recirculation with or without neutralization) the portable plant could be moved to another location.

Leachate recirculation can be applied to any landfill site, as can

neutralization, regardless of its location with a resultant decrease in time required for refuse stabilization. This fact may be very important in dry climates where, due to lack of sufficient moisture, landfills may take hundreds of years to reach complete stabilization.

The primary importance of leachate recirculation is that quantities of organic pollutants, and to some extent inorganic pollutants, released to the environment will ultimately be less than from a freely-leaching landfill. Recirculation can be improved upon by use of recirculation plus pH control, and possibly the addition of raw primary sludge if neutralization is immediate.

Research Continuation Procedures

The data collected to date have shown that leachate recirculation with or without pH control will increase the rate of landfill stabilization, reduce the concentration of pollutants in the leachate, and permit ultimate and controlled discharg with or without additional treatment. It has also been shown that recirculating fills with raw sludge seeding will require careful pH control to avoid destruction of the methane forming bacteria through accelerated volatile acid production and resultant decreases in pH. Continuing research is required to determine if the leachate from the control fill will reach the quality attained in the recirculating leachate after approximately three years. In addition, the benefits of digested sludge additions should be ascertained with and without pH control.

CHAPTER V
CONCLUSIONS

1. The recirculation of leachate through a simulated landfill more rapidly establishes an active anaerobic biological population within the fill which is even further enhanced by neutralization for pH control of the recirculating leachate.
2. Some of the inorganic content of the leachate is reduced as a consequence of biological activity promoted by leachate recirculation; further reduction of some of these inorganics is achieved with pH control.
3. The recirculation of leachate leads to an increased rate of biological stabilization of the organic fraction of the refuse; BOD, COD, and TOC are greatly reduced. Recirculation with pH control leads to an even greater biological stabilization.
4. The recirculation of leachate increases particularly the initial rate of surface settlement of the landfill site as well as total settlement during stabilization.
5. Leachate recirculation shortens the time required before a landfill site can be placed into ultimate use; this time is shortened further when pH control is used in conjunction with recirculation.
6. By using leachate recirculation, a sanitary landfill can be used as an effective treatment process for its own leachate; the treatment process is enhanced by the recirculation of leachate and neutralization.
7. Leachate recirculation can be used as a control method until additional treatment can be provided as required.
8. Landfills with leachate recirculation are more predictive as to needs for ultimate quality control and/or use of the site for various alternatives.

9. The addition of raw primary sludge to the refuse placed into a landfill will accelerate acid fermentation to the extent that it may overwhelm the buffer capacity and reduce the pH to a level detrimental to methane fermentation. The addition of a neutralizing agent for pH control must be accomplished in such a manner so as to avoid the reduction in pH and the inhibition of the methane population.

10. The ultimate effect of leachate recirculation is the reduction and control of total leachate pollution eventually discharged to the environment by a landfill and the improvement of the sanitary landfill method of solid waste disposal as a land reclamation method. If leachate recirculation is used with pH control (neutralization), the degree of leachate pollution is further reduced and the sanitary landfill method of solid waste disposal is further enhanced.

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